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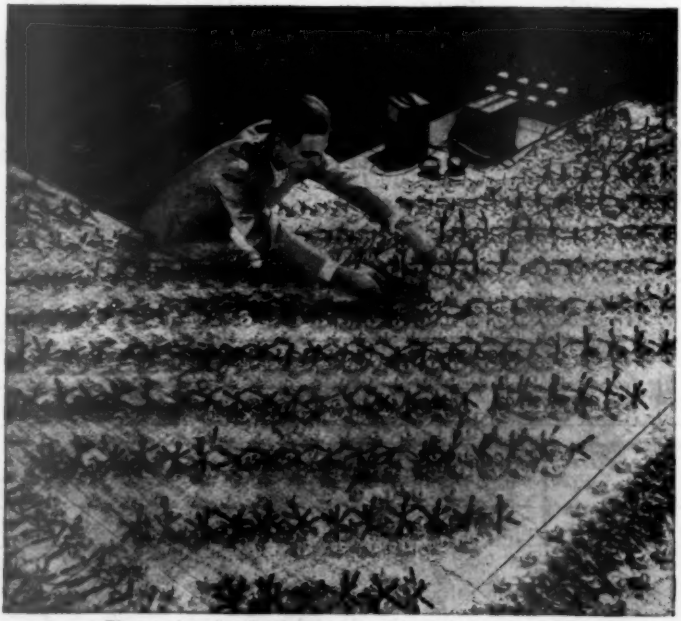
TECHNIQUES AND APPLICATIONS OF NUCLEAR SCIENCE AND ENGINEERING

February, 1950



Electrical analog for pile temperature studies; see p. 89

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NUCLEONICS

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The Atomic Industry and Human Ecology

VII—COOL, CLEAN WATER

THE LAMENT of thirsty cowboys as they rode the plains in search of water is matched by many industries today. Cool, clean water by the millions upon millions of gallons per day is used at Richland, Washington, Oak Ridge, Tennessee, and Chalk River, Ontario, by the atomic industry. Nor are the needs of the atomic industry unique in this respect; water is the biggest single raw material entering most chemical plants, and finding enough water to manufacture chemicals is no longer an easy job.

Cities have discovered problems in water supply, at least from the days of the Roman aqueducts up to (and including) the present "dry days" in New York City, and the various disagreements in the Southwest concerning disposition of water from the lower Colorado River. Cities must now supply large industrial users within their limits, as well as the greatly increased demands of individuals who take more baths, wash more clothes, and enjoy more adequate sanitary facilities than ever before in history.

According to *Chemical Engineering*, the U. S. uses 125 billion gallons of water per day. This is a per capita consumption of about 800 gallons per day—a far cry from the amount available when it was carried in buckets from springs or hauled up hand over hand from a deep well. Many of us today use more than 100 gallons daily for personal purposes alone, and the amount is not easy to decrease without hardship. Industrial users also find it difficult, or impossible, to decrease their water consumption quickly; processes and equipment designed to operate effectively and efficiently with water of a certain temperature and quality cannot be changed overnight.

Basic in importance from the ecological viewpoint being stressed in this series of brief essays is the fact that, for all practical purposes, the total amount of water on, in, and above the earth remains constant. The amount of water readily available and of acceptable temperature and quality, either at any one place or over large areas, may, and not infrequently does, change greatly. These changes are sometimes introduced by those immediately concerned in the area considered; more frequently they are introduced by one's neighbors "upstream."

The movement or transport of water from oceans, inland waters and wet soil, and by transpiration from plants amounts annually to 96,000 cubic miles. Total precipitation over land is about 24,000 cubic miles annually, some 9,000 cubic miles return to the oceans as runoff, and the balance is returned to the oceans by precipitation directly. In a very real sense the air-sea and air-land boundaries are of tremendous importance;

and the atmosphere is seen to serve as the transport medium of the entire great quantity of water (as vapor from evaporation and transpiration and then as precipitation after condensation).

There are variations, however, in the amounts of precipitation from place to place. Landsberg gives 476 inches precipitation annually at Mt. Waialeale, T. H., and 150 inches at Wynoochee Oxbow, Washington, as the highest mean annual rainfalls in the world and in the United States. As is well known, there are many square miles of land on which rain or snow rarely if ever falls.

The demand for water and the gross facts of its availability are as indicated briefly in the preceding paragraphs. Conservation in individual cases is often not only possible but less expensive than additional water. Waste products need not be loosed into streams for dilution in many plants; wastes recovered have not infrequently paid for the equipment installed and for its operation. Recirculation via cooling towers in the atmosphere or ground wells is often feasible.

When the problem is viewed in the large, however, it would appear that no one of the presently adopted plans (nor any combination of them) will satisfy the long term demands of man for water. The most obvious long term solution is to install large plants for the evaporation and cooling of sea water, a solution that will require much equipment, supplies, and manpower, even to supply water to coastal areas. With the use of large amounts of power from atomic plants, this solution may be applied in some areas in a few years.

Another and more subtle solution is suggested by the pioneer work of Irving Langmuir and Vincent Schaefer of General Electric. First by the use of dry ice pellets, and more recently by release of silver iodide vapor, these scientists have demonstrated to the satisfaction of most observers that, *under certain atmospheric conditions*, the distribution of rain or snowfall can be influenced inexpensively and certainly. Additional practical demonstrations of their methods have been made by Krick and others not only in the United States but in Australia and South Africa.

Up to the present time, in so far as public announcement has been made of the experiments, the "seeding" of the atmosphere by dry ice or by silver iodide has been done in essentially local areas. The results of such seeding are often spectacular in the formation or change of cloud forms and (sometimes) in the precipitation induced. Results are negligible or nil if the seeding is improperly done, and continued research is necessary to determine the correct methods and times for seeding.

Ecologically the possibilities of seeding the atmosphere are enormous. It is well known that winds aloft often carry dust and pollen for thousands of miles before they are brought to ground. The atmosphere knows no state nor national boundaries, and widespread changes in climate and weather are sure to follow if the seeding is carried on over large areas (even from a relatively few and inexpensive sources). The atomic industry and all other industries facing a water problem must begin now to learn about and to understand this new development.

Note: The preceding editorials in this series devoted to the subject of "The Atomic Industry and Human Ecology" were entitled: I—Waste Disposal (August, 1949); II—On Risk (September, 1949); III—On Getting the Word (October, 1949); IV—Relax (November, 1949); V—The Air We Live In (December, 1949); VI—On Uncertainty (January, 1950).

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PILE NEUTRON RESEARCH TECHNIQUES—I*

Development of the nuclear reactor as a rather unique research tool has opened up many new fields of investigation. This first of two articles tells how fast and intermediate neutrons are produced and made available for use. The special instrumentation necessary is described.

By D. J. HUGHES†
Brookhaven National Laboratory
Upton, New York

CHAIN-REACTING piles, or nuclear reactors, have been used as research tools for over seven years. The intense neutron fluxes available with piles in 1943 enabled some experiments to be made with ease which had been almost impossible the year before. More difficult experiments were performed as time passed, and the complexity of the techniques involved increased. Now, "pile research" is a distinct and ramified field of investigation.

PILES AS NEUTRON SOURCES

At the present time there are five chain-reacting piles in the United States more or less available for basic research. All but one are of the "thermal" type, with the moderating material they contain making the great majority of the neutrons of low energy. These thermal piles are: the original graphite-moderated pile put into operation at the University of Chicago in December, 1942, and now located at Argonne National Laboratory in Chicago; the deuterium-moderated pile, also at Argonne; the graphite pile at the Oak Ridge National Laboratory; and the "water boiler" at Los Alamos (which contains its uranium in solution in the water moderator). There is, in addition, one "fast" reactor, containing no moderating material, in operation at Los Alamos. Another thermal pile, the graphite pile at Brookhaven National Laboratory, Long Island, should be available shortly.

By far the great majority of the pile research has been done with thermal piles, and the present discussion is concerned primarily with this type. These piles, although differing somewhat in size and greatly in power level, are enough alike that it is possible to consider a generalized pile and its facilities for research without describing features peculiar to individual piles. Such a generalized pile will be described without going into complex diffusion theory or engineering details, the pile being considered simply as a source of radiation (*1*).

With the exception of the Los Alamos water boiler, all the research piles are of the heterogeneous type, consisting of unenriched uranium metal, in the form of lumps or rods, imbedded at regular intervals in the moderating material. The combination of uranium and moderator is called the pile "lattice," and it extends over a cubical or cylindrical region of dimensions the order of

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* Prepared under the auspices of the Committee on Nuclear Science of the National Research Council as a preliminary report of the Subcommittee on Instruments and Techniques.

† Part of this paper was written while the author was at Argonne National Laboratory, Chicago, Illinois.

meters. The lattice is pierced by some type of cooling ducts, and is surrounded, in turn, by a neutron reflector (usually of the same material as the moderator) and by a shield, as shown in Fig. 1.

The pile is run at the desired power level by adjusting various control rods containing a neutron absorber, such as cadmium or boron. When the pile is running at a constant power level, the number of neutrons produced per second by fission in the uranium must be exactly equal to the number which are absorbed or escape from the pile. The reproduction factor, k, (the ratio of the number of neutrons in the pile at a certain time to the number in the pile one neutron life cycle earlier) is then unity. When k is greater or less than unity, the neutron density in the pile will rise or fall accordingly. The value of k, and hence the pile power, is regulated by motion of the control rod, whose neutron absorption depends on position. The power is indicated by the current from an ion chamber (Fig. 1). The pile can be controlled by relatively slow motions of the rod, in spite of the fact that the average lifetime of the neutrons is about 10^{-3} sec, because somewhat less than 1% of the neutrons are emitted from the fission fragments several seconds after fission. These "delayed neutrons" cause the pile to respond slowly to slight changes in k and make control much simpler than it would be for "prompt neutrons" alone.

The neutrons emitted during fission in the uranium metal emerge from the metal with energies of the order of 1 Mev. The actual spectrum of these fission neutrons extends to higher energies, but the number of neutrons drops off very rapidly with increasing energy. The fast fission neutrons become moderated by elastic collisions with the moderator nuclei, absorption being relatively infrequent. The result of the collisions is that the neutron distribution becomes a "$1/E$ spectrum," in

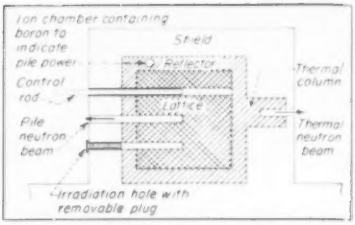

FIG. 1. Facilities for research in a pile (not to scale)

which the flux (defined later) of neutrons in a particular energy band is inversely proportional to the energy (*2*). The neutrons follow this energy distribution as they are slowed down, until they reach energies of the order of the thermal agitation energy of the moderator atoms. They then gain as well as lose energy and are known as thermal neutrons.

The neutrons in the pile spend by far the greatest fraction of their lifetime (which is about 10^{-3} seconds) as thermal neutrons; the great majority of neutrons in the pile are thermal. The quantity which is usually used in experimental work with the pile is not the number of neutrons, however, but rather the flux of neutrons, nv, where n is the number of neutrons per cm^3 and v their velocity (usually an appropriate average velocity). It happens that the flux of fast fission neutrons near the uranium metal in the pile is of the same order of magnitude as the thermal flux because of the great velocity of the fission neutrons.

The fission rate in the uranium, the fast neutron flux, and the thermal flux (which determines the fission rate) all vary spatially in a similar way through the pile. The thermal neutrons diffuse through the pile, reaching a low value at the surfaces or faces of the pile lattice. Thus, in a rectangular pile, the neutron distribution is in the shape of a cosine function, and in a cylindrical pile, a Bessel function. The distribu-

tion does not go to zero at the edge of the active lattice because some of the neutrons diffuse outward through the reflector. Because no fast neutrons are produced during this diffusion in the reflector, the neutrons become better thermalized as they diffuse. An extension of the reflector known as a "thermal column" usually extends through a hole about 5 ft square in the shield. The neutrons diffusing through this extra graphite become extremely well thermalized and reach temperature equilibrium with the graphite atoms.

It is important to consider quantitatively in as much detail as possible the neutron fluxes throughout the available piles. The usual figure that is quoted for the thermal neutron flux of a pile is the so-called "central flux," which may mean the flux in the moderator near the central uranium piece, or the average flux in the central uranium itself, the former being somewhat larger. For experimental purposes, where the flux available for irradiation is the significant quantity, the flux in the moderator is the more important value. Approximate values of the central flux have been declassified for several of the research piles and are given in the table. A recent report (7) describes an irradiation in the pile at Chalk River, Canada, with a maximum flux of 2×10^{12}.

As already stated, the flux of fast fission neutrons available in the most advantageous spot, that is, close to uranium metal, will be of the same order of magnitude as the thermal values given in the table. Both the fast and the slow flux drop off toward the faces of the pile; the neutrons can be made available for experimental purposes by means of holes penetrating the shield and perhaps the lattice.

Approximate Central Flux Values

	nv (*neutrons/cm² sec*)
Argonne heavy water pile (3)	1×10^{12}
Los Alamos water boiler (4)	1×10^{11}
Brookhaven graphite pile (5)	5×10^{12}
Oak Ridge graphite pile (6)	1×10^{12}

The flux of fast or slow neutrons available outside the shield of the pile at such an experimental hole can be calculated quite simply from geometrical considerations. For example, if a certain point beyond the end of an experimental hole can "see" a surface area 15 cm square (the base of the hole) at the center of a pile where the thermal flux is 10^{12}, and if the point is 10 meters from the center of the pile, then the thermal flux at the point is given by

$$nv = \frac{10^{12} \times (15)^2}{4\pi(1{,}000)^2} = 1.8 \times 10^7 n/\text{cm}^2 \text{ sec}$$

If the experimental hole did not extend to the center of the pile, the flux at the neutron radiating surface would be lower, but, on the other hand, the surface would be closer to the experimental point. Holes penetrating into the lattice give beams containing both fast and slow neutrons; these are usually referred to simply as beams of "pile neutrons."

The neutron flux in a thermal column decreases with distance from the pile lattice. The decrease is quite strictly exponential, dropping by the factor e per foot in a typical thermal column as the neutrons diffuse out of the column in the forward and sideward directions. In the thermal column of the Argonne heavy water pile, for instance, the flux of thermal neutrons decreases from about 10^{11} at the inner edge of the column to 10^7 at its outer surface. The number of fast neutrons in the column decreases much more rapidly, of course, and the neutrons become more thermalized as

they diffuse. A beam of thermal neutrons is usually obtained from the column by opening a hole of convenient size through the shield, and extending it into the thermal column itself. The flux at a point outside such an opening is then calculated from the geometry of the hole exactly as in the example given previously, but now the flux at the radiating surface is in the 10^7 to 10^{11} range, depending on the length of the hole. Thus a point 5 meters from a 15×15 cm surface where the flux is 10^{11} will receive a flux of 10^7.

The neutrons that emerge from such a hole in the thermal column are partially collimated and possess a Maxwell velocity distribution. The flux distribution, which is the more significant quantity in such a beam, contains an extra velocity factor and hence is given by

$$nv \sim v^3 e^{-v^2/v_0^2}$$

where v_0 is the most probable velocity. If such a neutron beam is detected by a counter whose sensitivity is proportional to $1/v$ (such as a small diameter boron trifluoride proportional counter), the response of the counter as a function of velocity will follow the usual Maxwell distribution (v^2 factor) because of the effect of the $1/v$ sensitivity. The "temperature" of the neutrons in a thermal beam is quite close to room temperature; that is, the most probable velocity ($v_0 = \sqrt{2kT/m} = 2{,}200m/s$ for $T = 293°K$) is about 2,200 meters per second. The measurement of the neutron temperature is somewhat difficult and will be discussed in Part 2.

The beams obtained from the thermal column or from the lattice itself contain, in addition to the neutrons, gamma and beta rays in amounts depending on the actual location of the hole. It is sometimes quite desirable to eliminate the effect of the gamma and beta radiation; this can be attained to a high degree by placing suitable filters, such as bismuth or lead, in the inner end of the hole. These materials have low absorption cross sections for neutrons of all velocities and, because of their location inside a diffusing medium, do not cut down the neutron intensity by scattering ("scattering out" of the beam is compensated by "scattering in"), but only by diffusion. This results in a much smaller decrease in neutron intensity than would occur if the filters were placed outside the pile. Some use has been made of reflection of neutrons by crystals and mirrors to separate slow neutron beams from the gammas and betas, but intensity is greatly sacrificed. The use of filters to modify the energy distribution in beams and to pick out specific velocities will be considered in connection with pile research techniques.

PILE RESEARCH TECHNIQUES

In describing the various techniques which have been developed for experimental use of pile neutrons, it is convenient to use a classification according to neutron energy. The customary energy regions for pile neutrons are *fast neutrons* (greater than 1 Mev), *intermediate or resonance neutrons* (1 Mev down to cadmium cut-off, about 0.4 ev), and *thermal neutrons* (below cadmium cut-off). These energy regions are only roughly defined, but they correspond very well to the classifications of the techniques developed for pile research.

Fast Neutrons

When chain-reacting piles first became available for research they were used principally for measurements with thermal neutrons, but recently more and more effort has gone toward utilizing neutrons of higher velocity. The principal method used to date in obtaining fast neutrons is by use of the neutrons emitted in the fission process

itself, usually referred to as "fission neutrons." Although the fission neutrons show a spread in energy of several Mev, they have proved to be quite useful for measurement of fast-neutron cross sections because of the advantages of the great intensity available and the possibility of estimating the flux accurately. The unmoderated fission neutrons have been used in two ways in pile research: by irradiation inside uranium in the pile lattice, and by use of a uranium "converter" outside the pile.

Pile irradiation inside uranium. If a material to be irradiated is placed inside a piece of uranium at the center of a pile, it will receive a flux of fission neutrons of approximately 10^{12} if the thermal flux in the region is of the same order of magnitude. The thermal neutrons which are present in the uranium can be eliminated by wrapping the material in sheet cadmium of about 0.03 in. thickness. The resonance neutrons which are present in the uranium are not removed by the cadmium and are quite likely to produce effects much larger than the fission neutrons because of high resonance cross sections. Boron, or other substances showing strong resonance absorption, can remove certain groups of neutrons if placed around the material, but the neutrons removed represent only a small fraction of the resonance flux. Because of the great range of neutron energies present, however, the method is not useful for measurement of fast-neutron cross sections which have an appreciable value over a wide energy range. The presence of neutrons of intermediate energy creates no difficulty for threshold reactions such as (n,p), (n,α), and $(n,2n)$, which usually have thresholds well over 1 Mev. Irradiation inside uranium is particularly well-suited for such reactions because their low cross sections necessitate high flux.

Because of the spread in energy shown by the fission neutrons themselves, it is somewhat difficult to interpret a measured cross section for a threshold reaction, especially for a light element which has widely spaced resonances in its cross-section curve. If it is assumed, however, that the cross section for a reaction such as the (n,p) or (n,α) rises in proportion to the penetrability of the potential barrier for the outgoing particle, from zero at the threshold to a point where the penetrability becomes unity, then the known shape of the fission neutron energy spectrum can be used to obtain the cross section from the observed activation. The cross sections for threshold reactions measured in this way have been used (*8*), however, in the reverse direction, that is, to estimate the shape of the fission energy distribution at very high energies from the observed cross sections. If the cross section for a certain threshold reaction is known, then it, together with the fission spectrum, can be used to calculate the yield of the reaction for irradiation inside uranium.

The method of irradiation inside a uranium slug is especially useful when it is desired to produce a radioactive isotope of high specific activity which can be made by a threshold reaction, because in that case chemical separation of the "carrier-free" radioactive product (that is, containing no inert atoms) is possible, as is never true for production by neutron capture. Several important isotopes, P^{32}, S^{35}, and Ca^{45}, for example, are produced by (n,p) and (n,α) reactions at Oak Ridge (*9*). The yield of such threshold reactions decreases with atomic weight because the determining factor is the penetrability of the residual nucleus, which decreases with increasing atomic weight.

Fast neutrons are very effective in dislocating atoms in solids because of elastic collisions. The displaced atoms

cause many changes in physical properties such as electrical resistivity, strength, and color. The high flux of fast neutrons available by irradiation inside uranium furnishes a useful tool for such solid-state problems.

It is possible to produce extremely fast neutrons of approximately 14 Mev in the pile by irradiating a solution of Li in D_2O with thermal neutrons. The H^3 nuclei produced in the $Li^6(n,\alpha)H^3$ reaction bombard the deuterons and produce the fast neutrons in the highly exothermic $H^3(d,n)He^4$ reaction. The yield of the over-all reaction is quite small (*10*) (about one fast neutron produced per 10^5 slow neutrons absorbed), and the reaction has not been extensively used. With the high intensities of thermal neutrons which are now available, the utility of the method for threshold reaction and solid-state studies should be investigated again.

Fission neutrons outside the pile. It is possible to obtain fission neutrons free from intermediate energy neutrons by placing a piece of uranium in a thermal beam. The thermal neutrons cause fission in the uranium with the emission of fast neutrons. The process thus "converts" the thermals to fission neutrons. The technique was developed by Hughes, Spatz and Goldstein (*11*) in order to measure activation cross sections for fast neutrons, a measurement which could not be made inside the pile because of the much larger effect of the intermediate energy neutrons. A plate of uranium metal is placed in a well-thermalized beam from the thermal column as shown in Fig. 2. The sample to be irradiated (usually in the form of a pressed pellet or "foil") is wrapped in cadmium and placed near the uranium. A bare foil of the sample is used to measure the flux of thermal neutrons striking the plate. The flux of unmoderated fission neutrons obtained is of the same order of magnitude as the thermal neutron flux striking the uranium, that is, of the order of 10^7 as discussed already. Although this flux is much less than that obtainable inside the pile, it is high enough so that activation cross sections as low as 10^{-4} barns can be measured by the resulting radioactivity of the foil. The fission neutron flux can be calculated quite accurately in terms of the fission constants of uranium and the thermal flux, which can be measured much more accurately than fast flux. The fission neutrons are obtained free from slow neutrons to such an extent that a substance such as gold, whose thermal cross section is 10^2 times the fast cross section, can be measured with no interference from the thermal neutrons. The spread of energy present in the fission neutrons is of no great disadvantage in the capture cross section work, for the cross sections at 1 Mev are averages over many resonances even for monoenergetic neutrons, and it is the average level behavior (level density) which is the main object of the cross-section measurements. The fission neutrons obtained with the uranium converter have been used for investigations of other properties of fast neutrons, such as the characteristics of fission induced by fast neutrons. Presumably they could be used for other studies as well.

Intermediate or Resonance Neutrons

After the fast fission neutrons have collided several times with the modera-

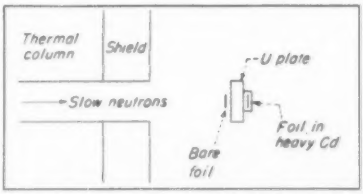

FIG. 2. Apparatus for obtaining fission neutrons outside the pile

tor nuclei, they reach a $1/E$ flux distribution (in which the flux of neutrons in the energy band dE is given by dE/E) and are then available for experimental use in the energy range from 1 Mev down to thermal. Neutrons of this extremely wide energy range are usually referred to in pile research terminology as "epicadmium" or "resonance" neutrons. Whether or not neutron resonances will be exhibited in this region depends on the particular nucleus and the part of the energy region under investigation. Actually, only that part of the $1/E$ spectrum below about 1 kev can be used to show distinct neutron resonances for average weight elements. The intermediate energy neutrons have been used extensively for research inside the pile lattice and in neutron beams extending outside the pile.

Inside pile lattice. When an isotope is subjected to the $1/E$ spectrum, the number of nuclear reactions that takes place is proportional to the integral of the cross section as a function of neutron energy multiplied by the flux density, that is, proportional to $\int \sigma dE/E$. This integral is the well-known "resonance integral" and is usually considered to extend from the cadmium cut-off, about 0.3 ev, up to fission energies. The form of the integral assumes that the dE/E spectrum is not distorted by the absorbing isotope, an assumption that implies extreme dilution of the absorber in the moderator. If distortion of the spectrum is present, the integral over the distorted spectrum is called the "effective resonance integral." The cross section under the integral is usually the absorption or the activation cross section, although the "resonance scattering integral" has as definite a meaning.

Measurement of the resonance integral gives no information on the cross section at a particular energy, nor does it tell the location of the resonances. It is a very important quantity for pile technology, however, because its value, for uranium and moderator, tells how many neutrons will be absorbed (hence lost to the chain reaction) in a thermal reactor during the process of slowing down of the neutrons from fission to thermal energies. The resonance capture of neutrons in a reactor depends markedly on the lattice geometry, and the minimizing of the effective resonance integral is an important phase of pile design. The resonance integral for activation can be measured from the resultant radioactivity of a sample, and the resonance integral for total absorption can be measured by the effect on the reactivity of a pile.

Resonance activation integral. In principle, the measurement of the resonance activation is quite simple. It involves only the irradiation of a cadmium-covered (to remove thermal activation) foil and subsequent measurement of the activity with a counter. In practice, however, it is sometimes very difficult to insure that the foil exposed to the resonance flux is thin enough so that no "self-protection" of the foil will occur. The condition of no self-protection is quite severe because the peak cross section at a resonance can be quite high. Indium, for instance, has a peak cross section of 30,000 barns; a foil must be less than 0.6 milligram/cm^2 thick in order that less than 1% of the neutrons of exact resonance energy will be absorbed. If the foils are sufficiently thin, so that all the atoms are exposed to the undistorted $1/E$ spectrum, the counting rate will be proportional to the activation integral—the exact constant of proportionality usually being obtained by comparison with some standard. Indium is quite a convenient standard because its resonance integral is determined almost completely from the large resonance at 1.44 electron volts,

whose shape has been well determined by velocity selector measurements (*13, 14*). The velocity selector measurements give the total cross section, but the cross section for activation of the 54-minute period can be obtained by correcting for the relatively small scattering and the contribution to the absorption of the periods other than the 54-minute. The value of the resonance absorption integral for indium determined by integrating the velocity selector curve in this way is 2,800 barns, accurate to about 5%.

Another convenient method for calibration of resonance activation measurements utilizes the "cadmium ratio" —the ratio of the activation of a bare foil of the material to the activation of a foil covered with cadmium, the foil again being sufficiently thin that self-protection is negligible. The cadmium ratio gives the ratio of the activation by resonance plus thermal neutrons to the activation by resonance neutrons alone. Hence, if the ratio K of the thermal flux to the integral of the resonance flux, and the thermal cross section σ_{kT} are known, then the resonance integral can be obtained from the cadmium ratio, R_{cd}:

$$\int \frac{\sigma dE}{E} = K \frac{\sigma_{kT}}{R_{cd} - 1}$$

The flux ratio K will depend on the particular pile lattice, but for a graphite-moderated pile the value of K is such that the cadmium ratio will be about 30 for a "$1/v$ absorber," that is, an absorber having negligible resonances and an epicadmium cross section which is solely the $1/v$ extension of the thermal cross section. Substances with appreciable resonance activation will have a cadmium ratio less than 30; indium, for example, has a cadmium ratio of the order of 2. The value of K for a particular pile can be determined by calibration with indium or with a strictly $1/v$ absorber, such as boron, whose resonance integral is easily calculated. The cadmium ratio is thus a quite sensitive and rapid method of detecting and measuring resonance activation, the main difficulty arising when a low cadmium ratio, hence possible self-protection, occurs. The measurement of several resource activation integrals from cadmium ratios is described by Seren (*15*).

Resonance absorption integral. The activation cross section is equal to the absorption cross section only when every neutron absorption results in a detectable activation. In many cases the activation is well enough understood that the absorption cross section can be correctly inferred from the activation cross section. However, for isotopes exhibiting extremely long or short half-lives or complicated decay schemes, the inference is difficult. In the case of the formation of stable isotopes, it is impossible. The total neutron absorption can be measured directly for such isotopes by observing the effect of the sample on the reactivity of the pile, since by this method every absorbed neutron is correctly measured, regardless of the nature of the reaction involved [with the exception of very unlikely $(n,2n)$ reactions that appear as negative absorption].

The effect of the absorption of resonance neutrons on the pile can be observed most easily by use of the "pile oscillator," which is an apparatus for inserting a sample into the pile at regular intervals. The reactivity, and as a result, the power, of the pile rises and falls with the same frequency as the sample oscillation, and the amplitude of the oscillation in power is proportional to the absorption of the sample (*16*). The pile oscillator has been developed both at Argonne (*17*) and Oak Ridge (*18*) National Laboratories, although mainly for measurements of thermal neutron absorption cross sections. The Oak Ridge oscilla-

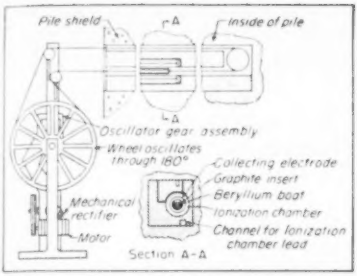

FIG. 3. Pile oscillator mechanical assembly. The portion of the drawing showing the graphite channel and ionization chamber has been enlarged to show details

tor, shown in Fig. 3, moves a sample, contained in a small beryllium boat, in and out of a hollow ionization chamber which measures the oscillation of the local pile power caused by the sample. The modification of the oscillator for measurement of the resonance absorption integral is used only at Argonne. In order to measure the effect of the absorption of resonance neutrons alone, the sample is oscillated inside a tube of cadmium extending to the center of the pile. In such a tube only the resonance neutrons are affected by the sample, and the amplitude of pile power oscillation is proportional to the resonance absorption integral if the sample is thin enough to eliminate self-protection. Absolute values of the absorption integral are obtained by standardization against a well-known substance such as indium or gold.

Although the oscillator has the advantage over the activation method that all the absorption is measured automatically, it has the disadvantage that any impurities in the material being investigated will likewise affect the pile.

Pile neutron beams. The methods just described for measuring the effects of resonance neutrons inside the pile lattice are useful mainly for measuring integral effects. Only a very few measurements have been made in which the $1/E$ spectrum inside the pile has been modified to isolate the effect of certain parts of the $1/E$ spectrum. Instead, the methods which have been used almost exclusively for measurement of cross sections at discrete neutron energies have made use of beams of neutrons emanating from the active lattice through holes in the shield (Fig. 1). The energy distribution in such beams of "pile neutrons" is the same as that in the lattice itself, consisting of the $1/E$ resonance spectrum and the Maxwell thermal distribution. Beams of pile neutrons have fluxes a thousandfold smaller than the fluxes inside the pile lattice, but this loss in intensity is compensated by the fact that discrete neutron energies can be isolated with neutron beams. Many approaches have been used to measure effects of different parts of the $1/E$ spectrum with pile neutron beams. No doubt additional methods will be developed, especially when higher fluxes of resonance neutrons become available. Actually, many of the methods to be described here find their most serious limitation in that the available flux in neutron beams from present-day piles is not high enough to use the instruments to the best advantage.

Resonance detectors. Some of the earliest cross-section measurements made with pile neutrons at energies above the cadmium cut-off were made with resonance detectors, which can be used to select a narrow band of neutron energies. Indium is a very useful detector for such measurements, because a thin foil of indium, surrounded by cadmium, will be activated mainly by neutrons of the indium resonance energy, 1.44 ev. In making the measurement, a collimated beam of pile neutrons is formed by shielding materials such as boron which stop resonance neutrons. The substance

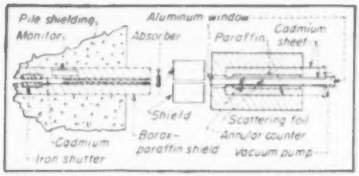

FIG. 4. Annular counter and shielding

whose cross section is being measured is placed in the beam. The activation of a thin indium foil wrapped in cadmium is used to measure the transmitted intensity. The ratio of the activation with to that without the sample, which is the transmission T, gives the total (absorption plus scattering) cross section σ_T of the sample for 1.44 ev neutrons:

$$T = E^{-N\sigma_T t}$$

where N is the number of atoms/cm³, and t is sample thickness. The transmission measurement is simple and rapid to perform, and gives quite accurate values of total cross section for neutrons of a particular energy. Cross sections at indium resonance and at thermal for a number of isotopes have been measured by J. Marshall (*19*) as a means of separating the absorption cross section (which varies as $1/v$) from the scattering cross section (which is roughly constant with energy).

Resonance detectors have been used recently in a somewhat more complicated way by taking advantage of scattering resonances as well as absorption resonances. The existence of resonance scattering for slow neutrons was first demonstrated by Langsdorf and Arnold (*20*) with pile neutron beams. If the detector in a transmission measurement is a thin foil of cobalt or manganese, as shown in Fig. 2, and if the intensity of neutrons scattered from the foil rather than foil activation is measured, then the observed transmission will refer only to those neutrons selectively scattered (resonance scattering) by the thin foil. As cobalt (*21*, *22*) and manganese (*23*) have extremely high scattering resonances at 100 and 300 volts, respectively, they can be used to measure total cross sections by transmission at these particular energies. In the work now being done at Argonne National Laboratory by Muehlhause and Hibdon (*24*), the scattered resonance neutrons are detected by a counter in the shape of a cylindrical shell (developed by Langsdorf). The collimated neutron beam passes down the axis of the cylinder (Fig. 4), at the center of which the particular scattering detector is placed. This method, like the absorption resonance method, gives accurate cross sections for quite precise neutron energies, its main limitation being the small number of resonance detectors available.

A recent refinement of the method of Muehlhause and Hibdon consists of using the resonance neutrons which are scattered from Co or Mn into a definite angle and hence with a definite energy loss, to obtain a wider range of energy values. The once-scattered neutrons are used as a monoenergetic source to measure the scattering cross section of a second material. The resulting low intensity, however, is a serious handicap.

Filters. Used extensively in early neutron work (*25*), the method of measurement of neutron resonance energies by absorption of the resonance neutrons in boron has been continued with pile neutrons. This method takes advantage of the fact that neutrons of a discrete energy are absorbed exponentially in a filter of boron. The $1/v$ absorption cross section of boron enables one to determine the energy from the rate of absorption. If a foil of a particular element is activated in a pile beam as increasing thicknesses of boron filters are interposed, then an analysis of the intensity of activation gives information concerning the activa-

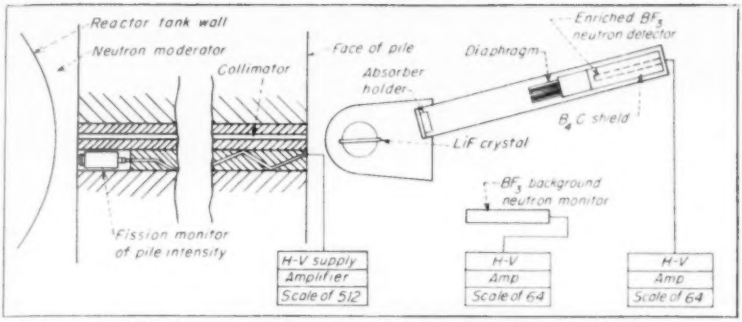

FIG. 5. Top view of apparatus for Bragg reflection of neutrons

tion cross section of the foil material as a function of energy. If, for instance, the material absorbs mainly at one resonance, then the activation would drop off exponentially with boron thickness, and the rate of decrease would give the resonance energy directly (for the decrease gives the boron cross section which, in turn, is accurately known as a function of energy). The detector, instead of being activated, can of course be arranged to scatter neutrons into a counter as already described; in this way the energy of a scattering resonance can be determined.*

If the absorption (or scattering) of the foil material is complicated, being made up of several resonances and the $1/v$ extension of the thermal cross section, then a detailed analysis becomes impossible, but some information can still be obtained concerning the average cross section as a function of energy. The filter method in the complicated case can be visualized crudely by considering the change in the distribution of neutron energies in the beam as boron filters are added, the average energy of the beam increasing with boron filter thickness.

Boron filters cannot be used at energies so high that the capture cross section of boron becomes small compared to the scattering cross section, because all sensitivity would be lost since the latter cross section is essentially constant with energy. Capture and scattering in B^{10} are about equal at 1 kev so that the filter method, even with pure B^{10} filters (instead of the normal isotopic constitution of 20% B^{10}) becomes useless at several kev. Activation cross sections as a function of energy have been measured by Lichtenberger *et al.* by using B^{10} filters in pile beams (*26*).

Crystal monochrometer. As soon as beams of resonance neutrons of high intensity were available, it became possible to make use of Bragg reflection at single crystals to select monoenergetic neutrons. Shortly after the heavy water pile was constructed at Argonne National Laboratory, the use of the crystal monochrometer was begun by Zinn (*27*). At about the same time a monochrometer was put into operation by Borst *et al.* (*28*) at the Oak Ridge pile. With the crystal monochrometer (Fig. 5) a well-collimated beam of pile neutrons is allowed to fall on a large single crystal at a small and adjustable angle, while the detector (usually a BF_3 counter) is set at such a position as to detect the reflected beam. The counter will then

* The energies of the scattering resonances in Mn and Co were determined by this method as described in references *21* and *22*.

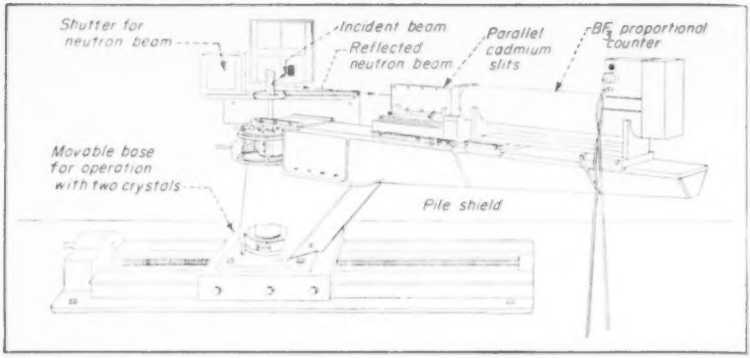

FIG. 6. Neutron monochrometer used at Argonne National Laboratory. Over-all length is about 12 feet

detect only those neutrons within a small energy, or wavelength, range centered at a wavelength given by the Bragg formula $n\lambda = 2d\sin\theta$ where θ is the glancing angle for the nth order reflection of neutrons of wavelength λ.

For a typical crystal such as LiF, the lattice spacing d for the third-order reflection is 4.01 A.U. If it is desired to select neutrons of one-ev energy, that is, of wavelength 0.28 A.U., then it follows that the glancing angle θ for LiF must be 3.5 deg. Selection of neutrons of 100 ev would therefore require a glancing angle of 0.35 deg. Because of the extremely fine collimation which would be required and because of the necessity of working close to the direct beam, it is not practicable to use existing crystal monochrometers above about 10 ev. It is possible that an instrument made up of many single crystals individually oriented and with extreme resolution in angle, could be built which would operate in the hundred-volt region, but none is contemplated at present. However, for neutron energies below 10 ev, the crystal monochrometer has proved exceedingly useful for analyzing neutron resonances (*29*, *30*).

The measurements that have been made with the crystal monochrometer in the resonance region have been mainly those of total cross section as a function of velocity, performed by measuring the transmission of a sample for different settings of the crystal and the detector. The monochromatic neutrons selected by a crystal could be used to measure scattering cross sections as a function of energy as well, but the low intensity of the scattered neutrons makes such measurements extremely difficult, as found by Beeman (*31*) with Cd and Weber (*32*) with In.

Because a high efficiency detector, usually an enriched BF_3 counter with its shielding, is quite heavy, the entire monochrometer becomes a rather heavy apparatus. The monochrometer in use at Argonne National Laboratory, shown in Fig. 6, has an over-all length of about 12 feet and is of massive construction.

The crystal monochrometer can be used for neutron velocities in and below the thermal region as well, but difficulty is encountered for the very slow neutrons because of interference from the more abundant faster neutrons reflected at higher orders (that is, with n greater than one in the Bragg formula). In the high-intensity thermal neutron region, the crystal is very useful as a source for diffraction studies.

Mechanical velocity selector, or fast neutron "chopper." Because of the large intensities of resonance neutrons available from piles, it is obviously desirable to develop a velocity selector which can be used for velocities greater than those which can be selected with the crystal. A mechanical velocity selector or chopper, designed to work at as high an energy as is feasible, has recently been put in operation by Selove (*33*) at Argonne National Laboratory, and another is being designed for use with the Brookhaven reactor. This chopper is essentially a rotating cylinder of iron, 4 in. in diameter and 16 in. long, with its axis in the beam of pile neutrons. The cylinder contains 6 radial slits 0.01 in. thick and runs at speeds up to 30,000 rpm. A similar stationary cylinder is placed in line with the rotating cylinder. Rapid, sharp (2 μsec duration) bursts of neutrons are produced as the moving slits pass the stationary slits. A counter 10 meters away detects these neutrons, and the counts are distributed among 80 scalers according to arrival time at the counter. Thus 80 velocity groups are selected simultaneously, and the total cross section of a sample (actually divided into six parts, one at each slit) can be measured. The chopper has a resolution and intensity of the same order of magnitude as the best that has been obtained with cyclotron velocity selectors and, in addition, has the advantage that very small samples, less than 1 gram, can be used because of the small slit size. Another advantage is that the apparatus does not tie up a whole machine but can be run simultaneously with many other experiments at the pile.

* * *

In the second of these two articles dealing with pile neutron research techniques, Dr. Hughes will deal with thermal neutrons inside and outside the pile and with neutron standardization.

BIBLIOGRAPHY

1. Several brief accounts of elementary pile theory may be found in: E. Fermi, MDDC-74 (1946); E. P. Wigner, MDDC-83 (1946); H. Soodak and E. C. Campbell, AECD-2201 (1948)
2. H. A. Bethe, *Revs. Mod. Phys.* **9,** 71 paragraph 59B (1937); H. Soodak and E. C. Campbell, AECD-2201, Part 1 (1948)
3. W. H. Zinn, MDDC-1073 (March, 1947)
4. R. F. Christy, MDDC-72 (June, 1946)
5. L. B. Borst, M. Fox, D. H. Gurinsky, I. Kaplan, R. W. Powell, C. Williams, W. E. Winsche, *Phys. Rev.* **74,** 1883 (1948)
6. R. T. Overman, AECD-1937 (1948)
7. L. Yaffe, B. Sargent, M. Kirsch, S. Stavdil, J. Grunlund, *Phys. Rev.* **76,** 617 (1949)
8. D. J. Hughes, W. D. B. Spatz, N. Goldstein, unpublished Manhattan Project results (1946)
9. "Radioisotopes," Catalogue and Price List No. 2, (Isotopes Branch, USAEC, Oak Ridge, Tenn., Sept., 1947)
10. H. L. Anderson, unpublished Manhattan Project results (1944)
11. D. J. Hughes, W. D. B. Spatz, N. Goldstein, *Phys. Rev.* **75,** 1781 (1949)
12. R. F. Taschek, A. Hemmendinger, G. A. Jarvis, *Phys. Rev.* **75,** 1464 (1949)
13. B. D. McDaniel, *Phys. Rev.* **70,** 832 (1946)
14. W. W. Havens, Jr., C. S. Wu, L. J. Rainwater, C. L. Meaker, *Phys. Rev.* **71,** 165 (1947)
15. L. Seren H. Friedlander, S. Turkel, *Phys. Rev.* **72,** 888 (1947)
16. A. Weinberg and K. Schweinler, *Phys. Rev.* **74,** 851 (1948); A. M. Weinberg, AECD-2044 (1948)
17. A. Langsdorf, *Phys. Rev.* **74,** 1217 (1948)
18. J. Hoover, *et al., Phys. Rev.* **74,** 864 (1948)
19. J. Marshall, *Phys. Rev.* **70,** 107 (1946)
20. A. Langsdorf and W. Arnold, *Phys. Rev.* **72,** 167 (1947)
21. F. Seidl, S. Harris, A. Langsdorf, *Phys. Rev.* **72,** 168 (1947)
22. S. Harris, A. Langsdorf, F. Seidl, *Phys. Rev.* **72,** 866 (1947); F. Seidl, *Phys. Rev.* **75,** 1508 (1948)
23. M. Goldhaber, A. A. Yalow, *Phys. Rev.* **76,** 100 (1949)
24. C. T. Hibdon and C. O. Muehlhause, *Phys. Rev.* **76,** 100 (1949)
25. H. A. Bethe, *Revs. Mod. Phys.* **9,** 69 paragraph 65A (1937)
26. H. Lichtenberger, R. Nobles, G. Monk, H. Kubitschek, S. Dancoff, *Phys. Rev.* **72,** 164 (1947)
27. W. H. Zinn, *Phys. Rev.* **70,** 102 (1946)
28. L. Borst, A. Ulrich, C. Osborne, B. Hasbrouck, *Phys. Rev.* **70,** 108, 557 (1946)
29. W. Sturm and G. Arnold, *Phys. Rev.* **71,** 556 (1947)
30. W. Sturm, *Phys. Rev.* **71,** 757 (1947)
31. W. Beeman, *Phys. Rev.* **72,** 986 (1947)
32. A. Weber, private communication
33. W. Selove, *Phys. Rev.* **76,** 187 (1949)

AEC Technical Information Program

The U. S. Atomic Energy Commission's research and development program, coupled with that of the Manhattan District, has produced an abundance of scientific and technical information. Much of it is the "know-how"—the trade secrets—of the new atomic energy industry. The first part of this article, written by Dr. A. F. THOMPSON, Chief of AEC's Technical Information Branch, and JOHN H. MARTENS, Assistant Chief of TIB, describes the present technical information program of the AEC, particularly with respect to the information available to the public. The second part is a staff report based on the Seventh Semiannual Report to Congress of the AEC.

RECOGNIZING the need for a practical "open door" policy, Congress stipulated in the Atomic Energy Act of 1946, "That the dissemination of scientific and technical information relating to atomic energy should be permitted and encouraged so as to provide that free interchange of ideas and criticisms which is essential to scientific progress."

Consistent with the policy expressed in the law, the Atomic Energy Commission is carrying out a positive program to speed the distribution of nonsecret technical information. In so doing, it works in close collaboration with the various laboratories associated with the Project in efforts to distribute the information through the established media, *i.e.*, books, technical journals, professional society meetings, *etc.*

A description of the technical information program should perhaps begin with definitions of some of the unique terms characteristic to the Project. "Restricted data," the information which cannot be released, is defined by the Atomic Energy Act of 1946 as "all data concerning the manufacture or utilization of atomic weapons, the production of fissionable material, or the use of fissionable material in the production of power, but shall not include any data which the Commission from time to time determines may be published without adversely affecting the common defense and security." Documents containing restricted data are marked "Top Secret," "Secret," and "Confidential," and are referred to collectively as "classified documents." It follows then that "declassified documents" are those which have been authorized for release from security restrictions. Another type of document considered in this work is the "unclassified document," which is a report dealing with nuclear research outside the area of restricted data and hence is never classified in any way.

To facilitate the development of unclassified information, the AEC has designated certain types of research as unclassified areas. The AEC imposes no security restrictions whatever on the publication of information developed in these areas by its contractors and associated laboratories. Rather the publication of the information on its own merits is encouraged. In general the unclassified areas include:

1. Pure and applied mathematics, except that applying to specific classified projects.
2. Theoretical physics (except the theory of fission, of reactors, and of neutron diffusion, and weapon physics).
3. All physical (except nuclear) proper-

ties of all elements of atomic number less than 90. Nuclear properties of most isotopes.

4. The basic chemistry of all elements (except for the analytical procedures and technology of the production of fissionable materials) and the physical metallurgy of all elements of atomic number less than 83.

5. Instrumentation, including circuits, counters, ionization and cloud chambers, neutron detectors (excluding fission chambers) electronuclear accelerators, such as cyclotrons, betatrons, Van de Graaff generators, *etc.*

6. Medical and biological research and health studies (excluding work with elements of atomic number 90 and above).

7. Chemistry and technology of fluorine compounds (except the specific application in AEC installations).

The declassification system, first organized by the Manhattan District to provide a means of authorizing the release of technical information after appropriate review and evaluation, is still the designated procedure for releasing all Project technical information except that which is included in the unclassified areas of research.

A committee of experts studied the problem of declassification shortly after the war and recommended policies. A centralized system was set up to declassify documents, a guide established that specified what types of information could be declassified—in general, basic science—and what technology was vital to production of fissionable materials and atomic weapons and could not be released. To interpret and apply the declassification guide, the AEC appointed about 100 scientists to serve as "Responsible Reviewers (RR)." In addition to their regular duties, these scientists examine the individual documents submitted for declassification and recommend action. The AEC also appointed four "Senior Responsible Reviewers (SRR)," prominent scientists who advise on policy matters and resolve borderline cases of declassification. Also, at each site a Coordinating Organization Director (COD) is appointed to handle declassification matters for the individuals at the site and to make the initial review and recommendation concerning papers originating at the site. The AEC's Declassification Branch consists of a relatively small number of scientists who administer the program; the Declassification Officer at Oak Ridge, Tenn., certifies actual declassification of each individual paper.

A Project scientist desiring to declassify a document, submits it to the COD of his installation. If release of the paper is in accordance with the organization's policies, the paper is forwarded to the appropriate responsible reviewer. It is then checked and forwarded to the AEC Declassification Officer with the COD and RR opinions. The Declassification Officer may, if necessary, refer the paper to an SRR for further review. He then formally approves or disapproves declassification on the basis of the reviewers' recommendations. If declassification is approved, the author can disseminate the information as he chooses.

When a paper submitted for declassification is found to contain data which is not releasable, this specific data is usually deleted so that the author can revise and issue his document.

It can be seen that the declassification system was designed primarily to serve Project scientists familiar with Project information and in a position to request declassification of specific documents.

The AEC research program is carried out by a large number of contractors located throughout the country. All of the contractors have their own information programs and policies, some well established through many years of operation. Nevertheless the contractor laboratories have all cooperated in establishing a systematic information program. The need for a rather centralized system developed principally

from the mutual interests of all sites in handling and distributing classified information. The centralized system is now used for the dissemination of unclassified information originating throughout the Project.

The Technical Information Branch of the AEC is responsible for operating the centralized phases of the work. Its functions are designed to serve both the Project and off-Project needs. In most cases the services rendered to Project and non-Project scientists are almost identical as pertains to unclassified information.

As mentioned before, the AEC encourages the publication of scientific information in the established journals. Perhaps it would be more accurate to say that the AEC relies on such publication since scientists in general seldom need encouragement to publish their work. Nevertheless, to promote publication, the AEC often accepts a published article as an adequate report of the work it sponsors, and certain research organizations are authorized to pay page costs and similar expenses associated with the publication of the work done in their laboratories.

As a supplement, the AEC has a rather limited program for distributing declassified and unclassified documents which are not otherwise published. In this case, the documents are reproduced and sold to the public at a nominal cost. In selling documents, the AEC acts as agent for the Government Superintendent of Documents, and all funds received are paid to the United States Treasury. At present about 1,030 documents are listed for sale. This is roughly one third the total number of declassified documents. Of the remainder approximately half have been published and half are to be included in the National Nuclear Energy Series. Only a small percent of the declassified documents is unavailable to the public. These are items such as brief abstracts of lectures, or drawings declassified for commercial purposes, *etc.* AEC documents are also available from the Department of Commerce (Office of Technical Services). Periodically the AEC issues price lists; the Government Printing Office, the Department of Commerce's OTS and a number of technical journals have listed available AEC documents. Henceforth, the AEC will issue semiannually its cumulative *Document Release Lists* of all available declassified and unclassified documents showing where they may be obtained.

One of the most important services rendered by the AEC is its program for the preparation of the National Nuclear Energy Series. Fifty to sixty volumes of declassified nuclear information developed within the atomic energy project are already scheduled.

During the war, when all research was divided into compartments, the various scientific groups made separate plans for preparing permanent records of their achievements. Later these groups agreed to combine their work in what are now the NNES volumes. Eight have been published so far.

Perhaps of most use to scientists interested in atomic energy is the semimonthly journal *Nuclear Science Abstracts* issued by the Technical Information Branch of the AEC. It contains abstracts of publications and documents relating to the field of nuclear science. The journal includes abstracts of all declassified and unclassified atomic energy reports and, as extensively as possible, covers technical publications, both foreign and domestic. Each issue is extensively indexed, and a cumulative index for all issues is prepared for each semiyearly volume.

Most digests are prepared by the Technical Information Division in Oak Ridge, but to broaden its coverage, the AEC has contracted with the John Crerar Library in Chicago to abstract pertinent articles in many periodicals.

Primarily for scientists within the AEC program, the journal has so proven its value to nuclear scientists generally that it has been made available to all. To facilitate the distribution of the journal, the Technical Information Branch at Oak Ridge is offering the journal in exchange for technical publications issued by other societies and institutions. *Nuclear Science Abstracts* is also available to the public on a subscription basis from the Technical Information Branch.

In addition to the services described above, the AEC technical information program includes special projects such as the preparation of a "Sourcebook on Atomic Energy," suitable for use by teachers and textbook writers. This book is being written by a prominent physical chemist and well-known author, Dr. Samuel Glasstone.

Another project originated in a survey by the Commission's Industrial Advisory Group. It proposed that efforts be made to select and declassify information of industrial value that had been developed by the atomic energy program. Accordingly, a trial program has been initiated. An advisory committee of representatives from industrial and scientific societies and technical press at a meeting with Commission representatives on September 1, 1949, suggested that a working party of experts be appointed, granted security clearance, and given access to necessary data. As representatives of various fields of industry, the working party would select information deemed valuable to industry. AEC will declassify the material where possible, and by a cooperative arrangement with the technical journals, it will be published. Original investigators will be credited and, when possible, invited to write and edit the material for publication. In this trial program, search will be limited to pumps, valves, blowers, instrumentation, and other developments involving metal work which probably can be declassified. Future plans will be based on the success of this first trial program.

It should be mentioned that the programs discussed here pertain strictly to scientific information. Of course much information which can be classed as technical is given out through official speeches and releases. Copies of all important speeches and releases are available from the public information offices at most AEC installations. Information for educational purposes is also available from the AEC in Washington, D. C.

Readers interested in obtaining more information or material concerning the technical information service are requested to direct inquiries to the Atomic Energy Commission, Technical Information Branch, P. O. Box E, Oak Ridge, Tennessee.

STAFF REPORT BASED ON AEC'S SEVENTH SEMIANNUAL REPORT

The dual purpose of the AEC as a producer and consumer of scientific and technical information, which would be difficult enough to achieve if all technical information was produced and distributed by one central office within the AEC, is further complicated by the Project's decentralized research and reporting activities. The AEC enters into contracts with universities, research institutions, industries, and individuals, calling for the performance of a research and development task. In many instances, the Commission receives a physical product, an instrument, or a weapon as a result of the contractor's work, but generally, performance under the contract is indicated by the transfer to the AEC of a piece of knowledge in the form of a scientific and technical report. In 1949, 350 research and development contractors

produced about 4,000 reports, of which 2,900 were classified and subject to security control and limited distribution. The balance were unclassified and, in principle, available to the general public.

All too often, it is supposed even by some scientists themselves, that the discovery of new knowledge in a laboratory is the beginning and end of the scientific enterprise; but without the structure of publication, collection, indexing, abstracting, *etc.*, the scientific enterprise would degenerate into a welter of repetitious fact-finding. In short, there is scientific advance because science is cumulative; each new discovery is based upon recorded and organized knowledge and, in turn, becomes part of the record for subsequent discovery. As summed up recently in a major address before the American Chemical Society, "publication is the lifeblood of science."

Classified Information

Scientists within and without the Project are accustomed to use and participate in certain established forms of scientific communication. The first step in scientific communication is the research report. This in turn becomes an article in a scientific journal, an item in an abstracting service, an index entry in a catalog, a chapter in a treatise, and ultimately part of the contents of a technical library. Since much of the research results of Project scientists falls in the area of "restricted data" and cannot be released to become a part of this regular pattern, the AEC has had to duplicate much of this pattern as a special system of communication within the Project. Corresponding to the scientific article destined for general circulation are classified reports which must be limited in circulation, but which also must be made available promptly to all other scientists within the Project who are working on the same or related problems. At the present time, most of these reports are circulated as individual documents, but the AEC has established one classified scientific journal, and is planning definitely to expand its classified journal program. The existence of classified journals in which their results can be published and disseminated is expected to help overcome the disinclination of scientists to work in classified areas.

Most classified reports are prepared in multiple copies by the individual laboratories and are distributed by them direct to one another. This direct dissemination avoids the delay of processing all reports through a central office, but it has necessitated a system of safeguards which is designed to insure that distribution is made only to authorized recipients. This direct though limited distribution is controlled by "Standard Distribution Lists." The AEC Division of Research, in agreement with other divisions concerned, prepares these Standard Distribution Lists which contain categories of distribution and define their scope. Each category appearing in the Standard Distribution Lists, *e.g.*, isotope separation, reactors, metallurgy and ceramics, *etc.*, is accompanied by a scope note which specifies what shall be included under each category and what shall be excluded. The listing of a name of a site laboratory, office, agency, *etc.*, under any category constitutes authorization for the distribution of reports.

The primary dissemination of research results in the form of a report or a scientific article is, as we have said, only one element in the pattern of scientific communication. Corresponding to such abstract services as *Chemical Abstracts* or *Physics Abstracts*, the AEC has established *Abstracts of Classified Research and Development Reports* (*ACRDR*). Authorized recipients of this publication are kept informed currently of all classified research in prog-

ress throughout the Project. Certain highly classified reports and reports of limited interest are omitted, however. *ACRDR* is issued twice monthly and in 1949, abstracted 1,630 reports and documents. Each copy of *ACRDR* is numbered and assigned to a definite recipient. Hence, with full regard for the requirements of security, *ACRDR* serves as an indispensable tool for digesting and collecting the diverse results of AEC classified research.

Once a report has been disseminated and abstracted, it takes its place in one of the many classified document rooms maintained by the AEC. More than 500,000 research and development reports are in organized collections in AEC libraries and document rooms. The Washington headquarters maintains a complete collection of all reports produced and the AEC document room maintained by the Technical Information Branch at Oak Ridge serves as a distribution center for supplying the collections maintained by the several contractors. These collections are not files, but highly organized repositories in which research reports take the place of ordinary technical books and journals. The Technical Information Branch catalogs all reports received and distributes cards to other document collections. A set of cards for an individual report consists of an author card, a report number card, and sufficient subject cards to comprise a complete subject index to the report. During 1949, 8,085 reports were cataloged and 2,485,886 cards were sent to 68 document rooms. The 8,085 reports cataloged represent 4,678 new reports; the balance of 3,407 is made up of reports which required recataloging and accumulated backlog from the war years. In the Fifth Semiannual Report, progress in eliminating this backlog was reported. The total elimination of the wartime backlog has now been achieved and cataloging of research and development reports is now on a fully current basis. A complete catalog of AEC reports now contains approximately 200,000 cards covering 38,000 reports.

Scientists use journals to maintain their awareness of current progress in their specialties; but such journals require to be supplemented with handbooks, compendia, and treatises. The AEC is preparing a series of such books as a classified part of the National Nuclear Energy Series. There will ultimately be 60 classified volumes in this series. During 1949, 12 volumes were edited and prepared for press.

Department of Defense

In May, 1948, the Military Liaison Committee formulated policies and outlined procedures establishing a program for the interchange of technical reports and information between the AEC and various agencies of the Department of Defense. Current classified and unclassified technical reports developed by research facilities of the AEC are

Behind the paper curtain

now moving on standard distribution to designated agencies of the Armed Services having a need for certain categories of technical information. Approximately 800 reports are furnished monthly to military offices and their research facilities. In addition, procedures have also been established for the handling of specific requests for the military for technical reports and information, including restricted data. Conversely, the AEC is currently receiving technical information developed by military agencies.

Unclassified Information

Whereas the classified technical information services of the AEC are designed to reproduce, as an isolated whole and within a limited area, the regular patterns of scientific publication and dissemination, the unclassified information services are designed to utilize and supplement this pattern.

The basic element of utilization of published scientific information is, of course, the collection of all journals and books which are likely to contain information relevant to the program of the AEC and its contractors; thus, throughout the Project there are active technical libraries serving laboratories and research installations. It should be remembered that many of the AEC's major laboratories are far from university and industrial centers, and research libraries have had to be built and staffed concurrently with laboratories and production plants. This does not mean that the AEC sets up a separate technical library for every research project which it sponsors. To the extent that research projects are located on university campuses or at established industrial centers, project personnel are able to use existing libraries. A new technical library is established by the AEC only in conjunction with a new major laboratory, in keeping with the policy set forth in the section on library facilities in the report of the President's Scientific Research Board (Steelman Report): "For those materials of frequent reference to be physically accessible to the research worker, the technical library has to be located in or near the laboratory. However, provision of adequate library facilities is an expensive task calling for trained personnel. These two facts, in combination, add weight to the conclusion found elsewhere that large laboratories are better than small isolated units. Only in the large laboratory can the expense of adequate library resources be spread over research operations extensive enough to make library cost a relatively negligible item of overhead." Thus, technical libraries supported by AEC funds are located at Oak Ridge, Knolls Atomic Power Laboratory, Mound Laboratory, Westinghouse Atomic Power Division at Pittsburgh, Brookhaven National Laboratory, Argonne National Laboratory, Los Alamos, Sandia, and Hanford where they service major laboratories, and at Washington for the use of the headquarters staff.

The AEC sponsors a considerable volume of unclassified research and also maintains a program for declassifying research results which no longer require security control. The unclassified and declassified reports have been released to the public in various ways. As a major method of dissemination the AEC encourages Project scientists to arrange for publication in established privately supported scientific periodicals.

The AEC's policy in this regard is supported by an overwhelming number of project scientists who do not wish to see the AEC or any other part of the Federal establishment assume the responsibility for publishing its contribution to research. Unfortunately, the private scientific societies are unable, at the present time, to publish the results of the greatly expanded present volume of Federally supported research,

including AEC research. And the AEC may be forced in the future either to provide financial assistance to private journals which publish information which the AEC is interested in disseminating or to inaugurate its own unclassified research journals. The National Research Council will shortly organize a conference of editors of the leading scientific journals in order to explore the extent of federal responsibility for the support of scientific publication. The AEC, along with other Federal research agencies, is awaiting the result of this conference before attempting to estimate the extent of its obligation to extend financial support.

In order to make sure that the services of the Technical Information Branch will be adequate to the research needs and aims of the AEC, the General Manager has established a Technical Information Committee consisting of representatives of the Research Division, Division of Biology and Medicine, Division of Military Application, Division of Reactor Development, Raw Materials Office, Office of Classification, and the Division of Public and Technical Information Service; and a Technical Information Panel representing the major contractors, as advisory bodies in the field of technical information. These two groups meet regularly to evaluate the effectiveness of existing technical information services and to consider plans for the extension of such services.

Processing of Information

To facilitate the processing of information, the AEC has joined with the Department of Agriculture in the development of a machine known as the Rapid Selector. The selector operates like a research worker looking through the cards in a library catalog, but at much greater speed. With properly coded entries, the machine will scan up to 120,000 subject entries per minute, compared to a dozen or two entries which a fast worker may examine in the same time. Moreover, it will reproduce, on the spot, an abstract of a document or, if properly set up, the original document, saving time now spent in searching shelves of local libraries or in waiting for the information to come from distant places.

First use of the selector by the AEC will be for the maintenance of records of new research with radioisotopes, which are among the most important research tools of modern science. Isotope information will be cataloged by physical characteristics such as the energy and type of radiation, by applications such as use in medical treatment and diagnosis, by method of production, and other factors.

Reproduction and Dissemination

The Joint Congressional Committee on Printing has authorized the AEC to maintain a field printing plant at Oak Ridge, for departmental printing. This plant reproduces *Nuclear Science Abstracts*, index cards, bibliographies, reports, *etc.*, for dissemination both within and without the atomic energy project. As noted earlier, the program of decentralized research and reporting provides for the preparation of reports for Project dissemination by the various contractors. When, however, a contractor lacks facilities for reproduction and dissemination of his reports, the Oak Ridge plant will reproduce such reports for Project distribution on the basis of a master copy prepared by the contractor. By agreement with the Joint Committee on Printing, all AEC publications which are intended for dissemination outside the Project and which are not thought to be suitable for printing at the Government Printing Office are published and disseminated by the Field Printing Plant at Oak Ridge. During 1949, the plant at Oak Ridge printed 25,000,000 pages. END

Desirable Improvements in Nucleonics Instruments*

A 5-million dollar instrument industry has sprung up since the end of the war. A pioneer in the field details here some of the growing pains of this industry and gives specific advice to both the manufacturer and the user.

By J. B. H. KUPER

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BEFORE THE WAR there was practically no industry concerned with nucleonics instrumentation. There was perhaps a handful of manufacturers producing Geiger counters and other special equipment for university laboratory use. Some of these manufacturers are still in business today, but the original handful is now hard to find in the group of competitors.

During the war the Manhattan District took extreme pains to conceal the fact that it was working in the field of nuclear physics, and, as a result, it was only very late in the war that any nucleonics instrumentation was put out on contract. Practically all of the equipment used in the development of the atom bomb and for protection of the workers at Oak Ridge and Hanford was produced within the Manhattan District itself. As a result, the equipment never went through the proper engineering development, such as it would normally receive if it had been contracted.

After Hiroshima, efforts were made to get industrial production of nucleonics instruments and, at the same time, to close down the production formerly carried on at the Argonne National Laboratory and its predecessor, the Metallurgical Laboratory.† We have now reached the point where we have too many manufacturers producing scalers and portable Geiger counter survey equipment. On the other hand, there are many types of equipment, of less general applicability to be sure, for which we have only a single source of supply, and, in some cases, not even that. It seems apparent that if all of the small manufacturers are to stay in business, some of them will find it necessary to diversify their lines and not concentrate so heavily on the instruments they consider to be of broadest commercial appeal, as the great majority do at present.

Since the equipment built under the Manhattan District's auspices never saw any appreciable amount of field service, but was used only under laboratory conditions, the components used and the general designs were definitely not suitable for long-term serviceability. The same is true of the early production of the various small manufacturers immediately following the war.

In the setting up and initial equipping

* Based on an address presented at the Second Annual Joint IRE-AIEE Conference on Electronic Instrumentation in Nucleonics and Medicine, November 2, 1949. The opinions expressed here are those of the author and do not necessarily represent the position of Brookhaven National Laboratory.

† See, for example, the article, "Survey of Nucleonics Instrumentation Industry," by R. E. Lapp, NUCLEONICS **4**, No. 5, 100 (1949).

of Brookhaven National Laboratory, practically all of the equipment had to be purchased from the postwar production, since the Manhattan District production had been geared very closely to the immediate demands, and little was available on surplus. I look back today at this early equipment and am a little startled, even now, at how poor it was in design and execution, from the standpoint of serviceability. The components used were of very poor quality and, in many cases, inadequate as to ratings. I believe that the troubles came more from poor workmanship and components than from poor original design, although both factors were undoubtedly present.

In the early postwar equipment, the two principal difficulties experienced were failures in high-voltage supplies for Geiger counters and short life, or generally poor performance, of the Geiger counter tubes themselves. Many major items of equipment were inoperative when received and, in several cases, never gave satisfactory performance. But, by and large, it was quite evident that test procedures were haphazard, to say the least. Also, we were plagued with shipping damage caused, in practically all cases, by slipshod packing methods. It was not infrequent that an elaborate piece of equipment, containing perhaps 30 tubes and costing well up towards a thousand dollars, would be packed in a shipping box with so little protection that the chassis would tear itself loose from the cabinet and the panels and knobs would get bent and broken.

To sum up the present status of the industry, we now have probably more than adequate competition among producers of a comparatively small number of items of wide general interest, and a great scarcity of producers of the more specialized items. The product being made now is far better in workmanship and in quality of components than it was two or three years ago, and much of the difficulty with shipping damage has been eliminated. However, there is still plenty of room for improvement in both of these respects, and we are still plagued by such problems as short shelf life of Geiger tubes.

DEVELOPMENTAL PROBLEMS

From the volume standpoint, the instruments designed for use in connection with health physics (or radiation protection) programs are, of course, the outstanding ones, so it may be well to consider them first.

Instruments used for radiation protection work can be divided into three major classes—*personnel* protection instruments, which are usually equipment very light in weight to be carried or worn on the person for evaluating the dosage received during the course of the day's work; *survey* instruments, usually portable, which are used to explore a laboratory or factory to locate sources of radiation in potentially harmful quantities and to evaluate with more or less precision the dose that will be received by a worker in any particular operation and location; and *monitoring* instruments, usually of a fixed or semiportable nature, to be set up at strategic locations around a laboratory or factory to warn of dangerous conditions.

Personnel Instruments

Instrumentation for personnel protection has progressed considerably since the early days when we used to carry, in a shirt pocket, a piece of dental X-ray film, with a penny snapped to it with a rubber band, as our means of evaluating dosage. While the principles remain largely the same, the pocket dental X-ray film has evolved into the modern film badge which usually includes two films, one of high and the other of relatively low sensitivity. The badge has a portion covered with a rather heavy shield and

another part comparatively open, so that some distinction can be made between hard and soft radiation. It may also incorporate a cadmium shield to provide some enhanced sensitivity for slow neutrons.

These devices are completely worthless in detecting alpha radiation and may give rather misleading results if a part of the body is exposed to beta rays. Where people are engaged in manipulating radioactive substances by reaching around a protective screen, smaller film badges in the form of wrist badges or film badge rings are often employed.

On the whole, this method is quite satisfactory as far as gamma-ray exposure is concerned, but leaves much to be desired where neutron exposure is known to be present. Where there is a known fast neutron hazard, the badge includes a special film (which is processed separately) to record fast neutrons by observation of the recoil tracks of protons in the gelatin of the emulsion. This requires a special processing technique, after which the films must be examined, under extreme high power, with a microscope. The neutron exposure is estimated then by counting the number of proton tracks found in a certain number of fields of the microscope. Needless to say, this method is rather tedious and results in considerable strain on the operators of the microscopes.

Supplementing the film badge technique, we have the various forms of pocket ionization chambers, which may or may not incorporate a quartz fiber electrometer so as to be instant reading. Ordinarily each laboratory worker is provided with two pocket chambers of the nonindicating variety. The fact that two are always used is an indication of the lack of reliability of these chambers. They are subject to accidental complete discharge if dirt is shaken loose in them or if they are subjected to severe shock. They may also be discharged through leakage across the insulator, particularly where it is exposed for charging. The pocket chambers are ordinarily read every evening, and if both chambers carried by an individual show an apparent exposure, the film badge may be developed at once instead of waiting to the end of the normal one-week period. By suitable choice of walls for the ionization chambers, it is possible to achieve a response approximating that of animal tissue to X-rays and gamma rays over a wide energy range. The chambers are ordinarily completely insensitive to alpha particles and will respond to only the most penetrating beta rays.

By lining the ionization chambers with boron instead of the customary graphite, it is possible to make them sensitive to slow neutrons, but it is rather more difficult to produce a chamber sensitive to fast neutrons. This can be done by coating the walls of the chambers with some material containing a large amount of hydrogen, but the over-all sensitivity is disappointingly low. The ideal thing would be to produce a chamber which would respond to mixed radiation, beta, gamma and neutrons of varying energies, in the same way that the human body does. If one interprets the word "respond" literally, this is clearly impossible, but some improvement over the present situation could doubtless be made. The problem is complicated, of course, by the fact that the chambers to be carried by an individual worker must not be very large, nor must they weigh more than an ounce or so.

Thus, we have reasonably satisfactory instrumentation for personnel protection against hard betas and gammas. We have no satisfactory means for dealing with external alpha particles or soft betas, but these are not considered to be problems in con-

nection with external radiation, since in general such weakly penetrating particles will not be able to get through the dead outer layers of the skin. The problem of ingested or inhaled alpha-emitting substances, and of infected cuts, is rather specialized and not amenable to solution by instruments worn on the person. This leaves the problem of detection of small quantities of neutrons, and most particularly of fast neutrons, as the major outstanding problem.

Survey Meters

Turning now to the portable survey instruments, we find that the overwhelming majority of them can be grouped into two classes, those employing counters and usually a counting-rate meter, and those in which some form of ionization chamber is used in connection with a miniature electrometer tube circuit. The portable Geiger counter instruments are very convenient for rough prospecting work, but, because of the vagaries of the usual Geiger-Müller tube, they are not dependable for precision quantitative work. In fact, at Brookhaven we do not calibrate these instruments, although they commonly are equipped with a scale reading in "mr per hour."

Our principal reason for not putting a calibration in mr per hour on our portable Geiger counter instruments is that we very often find people believing the meter indications and attempting to use an instrument designed and calibrated for gamma rays on a mixed beta-gamma radiation field, with results that are quite misleading. In principle, at least, one should be able to design a Geiger counter tube which would have something like a flat response to gamma and beta rays. However, as a practical matter, this appears to be very difficult.

In addition, we have the usual difficulties with the counter tubes (short life and instability of the plateau region with respect to temperature) so that we do not consider them for quantitative measurements. Instead, we use them for quick surveys to locate spills or regions requiring close study. With this point of view, it is an easy step to decide to leave out the count-rate meter altogether and simply provide a pair of headphones for monitoring the behavior of the counter audibly. A few instruments of this type have made their appearance on the market and more should follow. They are obviously cheaper and somewhat lighter than the conventional type with the indicating meter.

The various types of ionization-chamber, electrometer survey instruments suffer from a few common complaints. If they are provided with a thin window to let in alpha particles, the same thin window appears to let in an inordinate amount of moisture, and since they must necessarily operate with grid leaks of the order of 10^{11} ohms, or, in some cases, 10^{12} ohms, the problem of protecting them against humidity is a serious one. The development of a really good window material, thin enough to transmit alpha particles, yet impervious to moisture, would be a considerable help in this connection. Here again there is no problem in detecting hard betas or gamma radiation.

The ion chamber can be sealed up sufficiently well so that dependable operation is not too hard to secure. The problem then is principally one of battery life in the portable equipment. Chambers of this sort, however, are not of much use when it comes to dealing with neutrons, especially if the neutrons are accompanied by a gamma-ray background, as is usual.

There are a few other types of survey instruments which do not fall neatly into either of the two classes mentioned above, an example being the

"poppy," a portable proportional counter used for detecting alpha radiation. There has recently been a considerable amount of development work expended on various forms of the poppy-type of instrument, and it is to be hoped that this will soon bear fruit in the way of more serviceable equipment than has been available up to the present.

In addition to the proportional counter (which, after all, is a very old device, having been invented in 1908 or thereabouts), we have a revival of still another ancient method of measuring radioactivity—the scintillation counter. For much of our laboratory work in counting alpha particles, we have abandoned the usual ionization chamber techniques and substituted a scintillation counter, consisting of a zinc sulfide screen deposited on the wall of a photomultiplier tube. It is quite possible that some form of scintillation counter may turn out to be a more satisfactory instrument for alpha survey work than the poppy variety, since it appears possible to easily achieve a lower background or spurious counting rate with the scintillation counter than with the proportional type, and the high-voltage circuits requiring good insulation can be protected better from effects of humidity. It would be very desirable if a scintillation counter could be developed for neutron detection. Fast neutrons can presumably be detected by using one of the organic scintillating crystals, such as anthracene, but so far no one appears to have done this in a portable instrument. Slow neutrons might be detected by a crystal incorporating boron or some other substance exhibiting a high cross section for slow neutron absorption. Given a reasonably satisfactory detector for slow neutrons, one could use it to study fast neutrons, provided one can put a paraffin shield around it to slow them down. This procedure is not often possible for a portable instrument because of the large thickness of paraffin needed around an already large counter tube.

Monitors

The various types of stationary or semiportable monitoring equipment are usually too specialized to have reached any mass production stage at all and will not be considered here. Many of their problems are similar to those of laboratory counting equipment, which will be considered next.

LABORATORY EQUIPMENT

In a counting room, we have to deal with all types of radiation, although neutrons are present usually only in the neighborhood of a pile or an electro-nuclear accelerator, and very wide ranges of intensity must be measured. Depending on the type of experiment under way, we may have to measure the activity of a sample of phosphorus, then, after diluting it, feeding it to a rat and allowing time for its distribution in the rat's body, we recover small samples from various portions and must determine how much of the original activity went to the various locations. Perhaps only a few percent of the material administered was retained by the animal, and of this few percent any one organ may contain only a very small fraction, beside which the material has decayed considerably in the interval. As a result we have commonly to deal with counting rates which at one end tax the high speed capability of our equipment and at the other end may be only a fraction of the background which we have tried to reduce as low as we possibly can. Not only do we require a wide range of our equipment, but we also, for obvious reasons, require stability and permanence of calibration, at least over a period of a few hours.

The latter is not too easy to achieve with Geiger-Müller counters. Actually

I feel that these instruments are on their way out for precision work. Their advantages and shortcomings are remarkably similar to those of the superregenerative receiver. For those applications where we continue to use G-M counters, I recommend a Neher-Harper or multivibrator quench circuit. In this connection, a tube suitable for Neher-Harper circuits is very much to be desired.

In many cases we are tending to abandon the use of Geiger counters in favor of proportional counters of one sort or another. These have the advantages of comparative freedom from spurious counts, which are altogether too common with the Geiger counter, and ability to work at much higher speeds. Counting rates of the order of two hundred thousand a minute are not unusual. Another great advantage of the proportional counter is that under proper circumstances it is possible to study selectively the type of event in which you are interested. That is, it is possible to count alpha particles in the presence of a very strong gamma-ray background, or even beta particles accompanied by gammas. In addition, one can study energy distributions of particles or energy spectra by observing the distribution in pulse amplitudes resulting from the particles traversing the counter.

With proper conditions, the scintillation counters can be used in a proportional fashion. Therefore, much of what is to follow applies with substantially equal force to either the proportional or the scintillation types of counters.

To begin with, we have the problem of securing really stable high voltage supplies in the range from one to four kilovolts and, most particularly in the case of the proportional counter, with long term stability within a volt or so, regardless of changes in temperature and the like. These supplies need furnish only a negligible current. Usually the heaviest drain on them is that of the voltmeter itself, but we have found considerable difficulty in achieving sufficient stability, partly in that there is no very good source of reference voltage as yet. We have hopes that some of the newer gas discharge voltage regulator tubes may, with proper aging and possibly temperature control, furnish a really good reference voltage.

Generally speaking, the proportional counter output is at a rather low level, of the order of millivolts, in contrast to the order of volts in the case of the Geiger counter. As a result some form of pulse amplifier is needed before the pulses are counted. Where proportional response is desired, the amplifier is required to accept an extremely wide range of very fast pulses and still give a linear response. Amplifiers commercially available for this purpose are rather poor in respect to their overload characteristics, and we have found it necessary to do some development work of our own on this. Some preliminary work by members of our Laboratory has resulted in an amplifier with an acceptance range without overload of 7000 to 1. This is adequate for most proportional counter applications, but, unfortunately, we have not yet solved the problem of keeping the gain sufficiently stable. When we attempt to exploit to its utmost the ability of the proportional counter to distinguish electron energies, we find it necessary to keep the gain of the amplifier constant to within a percent or two. The output of the photomultiplier is, in general, at a higher level than that of the proportional counter, but the characteristics of the amplifier required for energy discrimination are very similar, although we can get by with less gain.

Following the amplifier, we urgently need some form of pulse height analyzer, preferably of the multi-channel variety (the type of instrument known to the British and Canadians as the

"kick sorter)." Offhand it seems a comparatively simple electronic problem to take a distribution of incoming pulses and sort them into, let us say, ten groups according to their height.

Unfortunately, in the present problem, this is not as easy as it appears, partly because the pulses to be measured do not have a definite uniform shape. Not only do they occur at random times with a wide range of amplitudes, but they usually have random variations in rise time. To avoid changing the pulse heights the amplifier must not distort the pulse shape; hence the amplifier must have stable gain over a very broad frequency band. Also it is of great importance that the widths of the individual channels remain constant, otherwise spurious peaks will appear in what should have been a smooth curve. When the sorting is done with biased trigger circuits, one is tempted to make the channels several volts wide to minimize the effects of contact potential drifts, *etc.*, but this only makes the design of the amplifier and shaper circuits more difficult because of the large amplitudes required.

When one sees a multi-channel "kick sorter" in all its glory occupying two full-size relay racks and containing several hundred tubes, one hopes for a simpler approach to the problem. It appears that some economies can be effected by resorting to some sort of beam deflection tube, a modified cathode ray tube with collectors representing the individual channels, instead of the complicated system of trigger circuits and anti-coincidence circuits used in the conventional analyzer. Unfortunately, this does not answer the whole problem because it is still necessary to scale down the counting rate in any one channel sufficiently to apply it to a mechanical register.

Various attacks on this problem of using a beam deflection method of pulse height sorting are being made at Los Alamos, Berkeley, Brookhaven and elsewhere.* However, for a great many experiments it is not necessary to have a multi-channel analyzer. A single sliding channel pulse analyzer can be used in many cases. This device is relatively simple to build, although still not entirely free of the difficulties of the sort mentioned above, but none is presently available commercially. This seems to be a lack which some enterprising manufacturer should fill promptly.

Finally we come to the question of the scaler, which is necessary in practically all cases to cut the counting rate down to something reasonable to apply to a register. Most of the commercial scalers were designed specifically to work with Geiger-Müller counters and have a speed capability appropriate for that type of service. However, when one tries to take full advantage of the speed of a proportional counter, not to speak of a scintillation counter, it is clear that scalers appreciably faster than those now generally built are needed.

DECADE vs BINARY SCALERS

At present, there seems to be a lamentable tendency to turn to decade scalers rather than the binary type. The advantage claimed for the decade scaler is that it is easier for untrained personnel to record data without making mistakes and to properly interpolate between register indications. However, there are usually very few cases arising in ordinary experimental work in which it is worthwhile to use the interpolation between register counts, providing, of course, that the scaling factor in use is appropriate to the activity level being studied. Fortunately,

* See, for example, "Pulse Height Distribution Analyzer" by W. E. Glenn, Jr., NUCLEONICS **4**, No. 6, 50 (1949), and "The Ten-Channel Electrostatic Pulse Analyzer" by D. A. Watkins, *Rev. Sci. Instr.* **20**, 495 (1949).

it is permissible not to bother to reset the scaler, but only the register, and the error committed in most cases is quite negligible. On the other hand, the ordinary decade scaler has tubes and other parts in it enough to make a scale-of-16, yet a factor of 10 is all that is achieved. In addition, the system for interpolation is rather elaborate and very often can get out of adjustment. We have found that servicing of decade scalers is far more difficult than of the binary type, and we seriously question whether the convenience in interpolation is worthwhile. When you are responsible for maintenance of several dozen scalers the servicing problem looks important.

The fashion in scalers nowadays seems to be to build a decade unit as a plug-in device which can be removed when servicing is necessary. This turns out to be not nearly as convenient as one might suppose, since it is necessary to build some sort of special test rig in which to service the plug-in unit when it has been removed from its regular chassis.

There is now a tendency on the part of manufacturers to attempt to build equipment which will answer all possible demands and so provide alternate types of operation, such as predetermined count as well as predetermined time, and perhaps also a count-rate meter. While there is much to be said for making instruments for general application and making them as flexible as is consistent with good performance, it is highly questionable whether these alternative types of operation have any real value.

Operation of a scaler for a predetermined time usually requires slightly less circuitry than the predetermined count, but this advantage will disappear when registers with built-in contacts become more common. The choice of method will probably depend on the amount of further computation required to obtain the result in useful form; in many cases the predetermined count is awkward since it is necessary to take reciprocals when subtracting the background. The advantage that all counts have the same statistical accuracy may be illusory since there are many other factors affecting accuracy besides the randomness of nuclear events. Perhaps some of my preference for the predetermined time method stems from a feeling that the statistical fluctuations are being given too much prominence in comparison to the other errors.

As one of the perpetrators of one of the very first counting-rate meters ever built, I feel that this device has crept into many places where it does not properly belong. It is most useful where it is necessary to record a slowly varying activity level, and in some portable equipment. However, one sometimes sees the statement made that it is applicable where it is desired to get a quick rough estimate of the activity of a given sample. In the ordinary method of using a counting-rate meter, it is not possible to save time over the use of a scalar. As a matter of fact, to attain any given accuracy takes approximately 2.3 times as long with the count-rate meter. If one is willing to fiddle around with the time constant switch during the course of taking the reading (or to push buttons which move the meter needle faster in the direction in which it appears to be going) one can achieve a result exactly equal to that attained with the conventional scaler and stop watch. The best that can be said for the count-rate meters is that, by and large, they do not take very many tubes, and so are not a serious drawback to a piece of equipment.

I should be disappointed if these last criticisms are taken as aimed at the manufacturers. On these particular

(Continued on page 45)

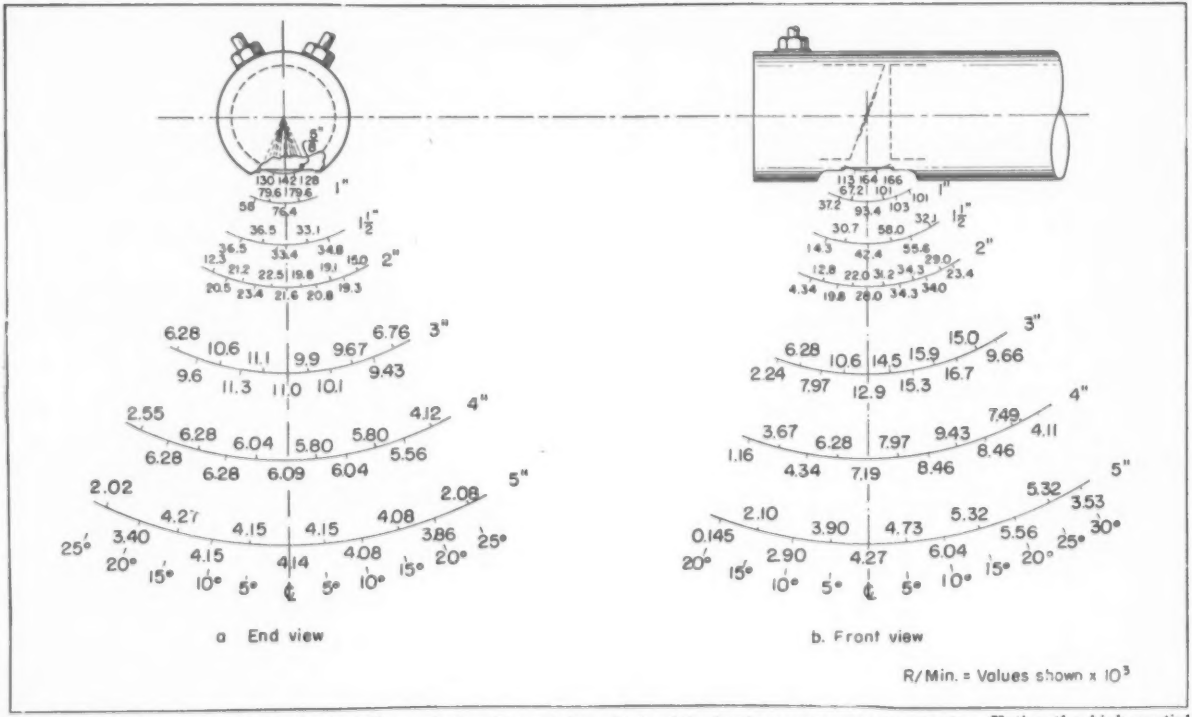
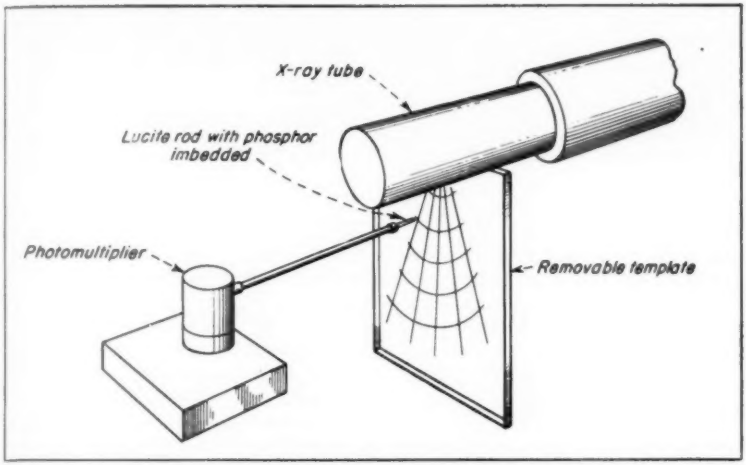


FIG. 1. Roentgen dosage field of a beryllium-window X-ray tube, obtained by luminescence measurements. Notice the high spatial resolution, impossible to obtain with available ionization chambers



Measurement of roentgen rates by luminescence of phosphors is feasible. It now seems possible to replace the presently used ionization standard with a luminescence standard. The apparatus above was used to obtain the dosage configurations given on the opposite page.

Luminescence Measurement of Roentgen Dosage*

By BENEDICT CASSEN and LAWRENCE R. CURTIS

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FOR SOME BIOLOGICAL EXPERIMENTS requiring administration of high dosages in a small volume, it is both necessary and desirable to obtain a detailed dosage distribution around the window of the X-ray tube and to obtain dosage measurements accurate to at least 10 to 15%, for the particular tube and voltage waveforms to be used. There is no commercially available instrumentation for making these determinations, and the significance of the r unit for soft radiation measurements is not entirely clear. Because of this, a rather new point of view has been taken.

Previous results (*1*) showed that luminescence of a small grain of X-ray phosphor could be piped through a lucite rod to a photomultiplier tube if the luminescence was sufficient. In a phosphor consisting only of very low atomic number materials (a purely organic compound perhaps), the luminescence would be a result of Compton recoil electrons causing electrons in full energy bands to jump into conduction bands. Then, whatever the nature of the ensuing luminescence mechanism, if no saturation effects occurred, the luminescence should be proportional to

*This paper is based on work performed under Contract No. At-04-1-GEN-12 between the Atomic Energy Commission and the University of California at Los Angeles.

FIG. 1. Roentgen dosage field of a beryllium-window X-ray tube, obtained by luminescence measurements. Notice the high spatial resolution, impossible to obtain with available ionization chambers

the energy per cm³ per sec liberated as kinetic energy of recoil electrons. It should therefore be proportional to the ionization produced per cm³ per sec in a material of approximately unit density. It appeared that, if a suitable material could be found, it could be used, after proper calibration, to determine roentgen units per unit time under conditions where it is impractical or impossible to use an ionization chamber.

It was found visually that several organic crystalline compounds, notably anthracene and chrysene, showed moderately bright luminescence when exposed to X-rays. Different brands of chrysene showed different colors and had different brightness efficiencies. Anthracene was usable but deteriorated under very high dosages.

Wilson (*2*) has reported the fluorescence of polymerized plastics on exposure to X-rays and has speculated on their use for photographic dosage determinations. On the suggestion of Dr. Stanley L. Whitcher of this laboratory, polyvinyl carbazole was tried. Not as bright visually as the chrysene, it was comparable to the anthracene. After a series of tests for lack of saturation and for proportionality, it was found to be a suitable material for the purpose. As it can be polymerized in large optically clear pieces, it offers interesting possibilities for further types of application.

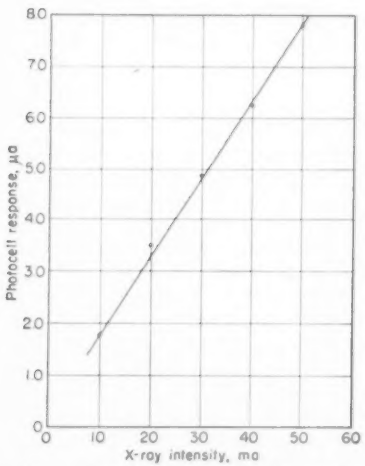

FIG. 2. Photocell response is linear with X-ray intensity measured in milliamperes

Preliminary Luminescence Tests

Two initial tests were made relative to the variation of the luminescence of a small piece of polyvinyl carbazole plastic. A 50 kilovolt, end-ground, water-cooled, beryllium-window X-ray tube (*3*), operating up to 50 milliamperes, was used. The roentgen unit output of this tube in a small spatial region close to the beryllium window has been estimated to be in the neighborhood of 2,000,000 r per minute (*4*). This estimate was obtained, with constant potential operation, by Braestrup by use of a thin-walled ionization chamber placed 10.0 cm from the center of the focal spot and by extrapolation to 2.0 cm by means of the inverse square law. But these tubes are usually excited by a full-wave voltage generator and Braestrup's constant potential output estimate does not hold.

The first test was designed to determine whether any saturation effects existed over the range of intensity used. This was done by plotting the photomultiplier amplifier output against the X-ray milliamperes of the beryllium-window tube operating at 50 kv, with the plastic pickup almost in contact with the beryllium window. The results are shown in Fig. 2, and clearly indicate the essential proportionality of luminescence and X-ray intensity over a very great intensity range.

The second test was designed to determine whether the expectation that the luminescence per r per minute was reasonably independent of the X-ray voltage could be verified. The results are shown in Fig. 3. One set of read-

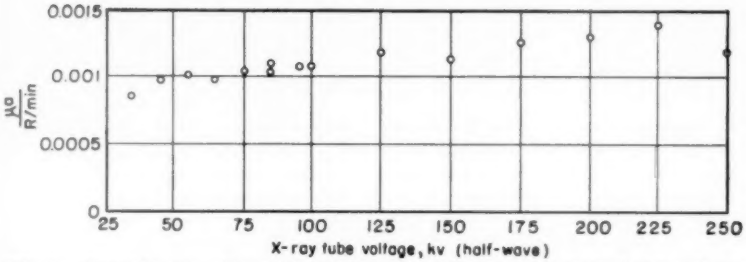

FIG. 3. Dependence on X-ray tube voltage of luminescence of polyvinyl carbazole per r/min

ings from 40 to 85 kv was obtained from a portable radiographic unit. Another set, from 85 to 250 kv, was obtained from a 250-kv therapy machine. The output of the photomultiplier amplifier was checked against an accurate microammeter and compared with readings obtained from a Victoreen thimble chamber dosimeter.

With the possible systematic errors that could arise, either from the photomultiplier measurements or the ionization chamber measurements, the results of Fig. 3 are considered to be fair substantiation of the expected proportionality. There does seem to be a trend in the direction of there being more absorption effect with the plastic pickup arrangement than with the thimble chamber. More refined measurements should eventually be made, especially if it is found desirable to define roentgen rates in terms of light quanta produced instead of ion pairs produced per unit time per unit volume. This possibility seems to be very worthwhile considering for very soft X-ray dosage measurements.

As the voltage range of the diagnostic unit used for calibration of the plastic pickup joined on to that of the beryllium-window tube, it seems very probable, although not logically proved, that the pickup measures roentgen units per minute in the dosage field of the beryllium-window tube. This should be regarded as a reasonable assumption which as yet cannot be tested absolutely.

Output Measurement Apparatus

The point-by-point arrangement used for making output measurements from the beryllium-window tube is diagrammed on page 35. The template was used only for alignment purposes and was removed during actual measurement. For obtaining readings close to the window, the probe was slightly inclined so that it could be placed in the recess near the window. A test of the assembly with the luminescing plastic removed showed that there was negligible background pickup, and that the lucite rod and surrounding material did not luminesce.

The lucite rod was not aluminized, but was surrounded, except for the tip, by a concentric brass tube of a sufficiently larger diameter to leave a definite air space between the rod and tube. The presence of this air enabled ordinary internal total reflection to reflect the light along the rod to the photomultiplier tube.

The end of the rod was formed into a parabolic shape as described in reference *3*. The luminescent plastic was inserted in a hole drilled to the neighborhood of the focus of the parabola. The tip was surrounded by thin black paper which had been previously tested for light opaqueness and negligible absorp-

tion of soft X-irradiation. Measurements were made in a semidarkened room to avoid any leakage effects.

Output of the photomultiplier tube could be read directly on a sensitive, accurate microammeter, or it could be fed to a d-c amplifier with four amplification scales. The amplifier was calibrated against the accurate microammeter. The completed apparatus was frequently checked for roentgen rate calibration by comparing its reading against thimble chamber readings on the 85-kv portable machine.

Experimental Results

Dosage field values obtained with this apparatus are shown in Fig. 1. The beryllium-window X-ray tube was operated at 50 kv and 30 ma. It could be operated at 50 kv and 50 ma; if so operated, the r/min values shown should be multiplied by 1.67.

Of interest is the maximum rate so obtained. The maximum measured rate at 30 ma is 166,000 r/min; this value was obtained a little to the cathode side of the center of the window. This is equivalent to 276,000 r/min at 50 ma. The value on the center line of the window is only very slightly less. It is 164,000 r/min at a point which is 1.6 cm from the center of the focal spot. At 5.0 cm from the focal spot, the value is 28,000 r/min.

If this latter value is extrapolated back to 1.6 cm by the inverse square law, it would give an expected value of 274,000 r/min which is 1.67 times the measured value. This shows that there is considerable deviation from the inverse square law near the window. Probably the previously estimated values of Rogers and Braestrup for output at constant potential operation are quite a bit too high. Between 5.0 cm and 10.0 cm the inverse square law is fairly well obeyed. The ratio of measured values is about 3.9; theoretically it is 4 if air absorption is neglected.

One of the most striking features shown by Fig. 1*b* is the very large "heel effect" produced by absorption in the target of soft components of the radiation originating from a slight depth in the target. This effect has been observed by Lewis and Mutscheller (*5*) for tube operation between 6 and 14 kv. The inaccuracy of the measurements shown in Fig. 1*b* makes it impossible to determine the exact angle of the maximum intensity, but it is obviously somewhere in the neighborhood of 15 degrees towards the anode side. In contrast, the values in the plane at right angles are fairly symmetrical around the center line, as shown in Fig. 1*a*.

It should be noted that relative intensities as determined by this method are fairly accurate, even though the basic assumption for the determination of absolute values might be a little in error. This error cannot be great, however, as the relative values show the unsuitability of using the inverse square law for extrapolation to short distances. A corrected extrapolated value of Rogers and Braestrup would give a constant potential output at 50 kv, 50 ma of somewhat over a million roentgens per minute instead of somewhat over two million roentgens per minute. The first figure would be in better agreement with the quarter million roentgens per minute observed with full-wave operation. These comparisons are subject to further check.

BIBLIOGRAPHY

1. Benedict Cassen and Lawrence R. Curtis. Measurement of ionizing radiations *in vivo*. *Science* **110,** 94 (1949)
2. C. W. Wilson. Fluorescence of highly insulating dielectrics produced by X- and gamma radiations. *Nature* **161,** 520 (1948)
3. T. H. Rogers. A high intensity source of long wavelength X-rays. *Ind. Radiography* **4,** 35 (1945–6), and Machlett Laboratories, Inc., catalog on tube type AEG-50-T
4. T. H. Rogers. Radiation from beryllium-window tubes. *Radiology* **48,** 594 (1947)
5. Lewis and Mutscheller. Quality, intensity, and field distribution of radiation emitted from a new type of roentgen therapy tube. *J. Investigative Dermatol.* **12,** 325 (1949)

A Proportional Counter X-Ray Spectrometer

Useful for the energy range of 1 to 50 kev, this instrument provides a simple method for measuring X-ray spectra. Graphs show the effects introduced by different counter materials and filling gases, and resolution and linearity are described.

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USE OF PROPORTIONAL COUNTERS for determining low-energy beta and X-ray spectra has been described by several authors (*1*, *2*, *3*). The method these counters provide for identifying unknown X-rays is simpler than that provided by Geiger-Müller counters for critical absorption measurements.

The instrument described on the following pages was designed for X-rays in the 1–50 kev energy range.† Since the output pulse amplitude from a proportional counter and amplifier is given by:

$$dv = \frac{A_a A_g (E_p/E_i) \times 1.6 \times 10^{-19}}{C}$$

where A_a = amplifier gain, A_g = gas amplification factor, C = capacitance in farads, E_p = photon energy in ev, and E_i = ionization potential of the gas in ev, the amplitude can be used as a measure of the photon energy. The X-rays lose all their energy in the ejection of one electron from one of the electron shells of the counter gas, and the ionization caused by this secondary particle is detected. This method is useful only for low-energy X-rays where the Compton scattering is negligible.

The energy transferred to the secondary electron is equal to the incident X-ray energy minus the binding energy of the shell from which the electron is ejected. The effects of the particular shell from which the electron is ejected will be described later. The spectra of different elements are determined by sorting the output pulse amplitudes with a pulse-height analyzer.

Conditions Affecting Counter Components

Several conditions must be satisfied to maintain the linear dependence of the pulse amplitude upon the particle energy.

The output pulse height must not vary with the location, within the sensitive volume of the counter, where the ionization is produced by the secondary particle. This condition necessitates the use of spectroscopically pure gases and sealed, clean counters. Introducing even trace amounts of an electronegative gas results in negative-ion formation.

The counter center wire must be large enough to reduce the probability of recombination in the low field region near the cathode.

The dimensions of the counter must be large compared to the maximum path length of the ionizing particle in the sensitive gas volume. If an appreciable fraction of the secondary electrons dissipates only a portion of their total energy within the counter, the spectrum is distorted because such electrons would be recorded as having lower

* Deceased.
† This work was done under the auspices of the U. S. Atomic Energy Commission.

energy. Also, the low field region at either end of the counter must be kept at least one counter diameter away from the counting volume to prevent particles from entering this region. Thus, higher-energy events make a larger counter necessary, and this requirement limits the useful operating range.

The gain of the amplifier must be independent of small changes in pulse shape. There is a spread in the rise time of proportional counter pulses of from approximately 0.3 to 0.8 μsec depending on the location of the ionizing event within the counter. A variable amplifier gain will again result in a distorted spectrum. Also, shifts in the amplifier baseline, usually caused by overloading of the amplifier, will have a similar effect. Because the gas amplification factor is a rapidly varying function of the voltage, the high voltage must be held stable to ~0.01% of operating voltage for good of resolution.

If these conditions are satisfied, the spread in the output pulse amplitude is dependent upon the statistical nature of the multiplication process. This variation is not large enough to impair instrument resolution seriously.

The low-energy limit of the instrument is dependent upon the gain of the amplifier, the mput tube noise, and the amplification factor. In the proportional region the amplification factor is an exponential function of the high voltage, and it is not dependent upon the particle energy. At amplification factors greater than 10^8, the relationship is no longer exponential, and there is a differential amplification dependent upon particle energy. It is possible, therefore, to operate at amplification factors as high as 10^7, but instrument stability is poor because of extreme sensitivity to variations in high voltage.

The counting of mixed sources introduces the problem of a broad pulse-height distribution. The amplifier should handle a pulse-height ratio of 1,000 to 1 without the introduction of long deadtimes or spurious counts.

Assembly

The particular instrument described consists basically of a counter, preamplifier, amplifier, high-voltage supply, pulse-height analyzer, two scalers, and registers.

Figure 1 is an assembly drawing of one of the counters used in this work.

Brass tubing, 9 in. long, and 3 in. in diameter, is used for the counter. The center wire is 3-mil wolfram; it is supported at either end by the Kovar seals. The heavy leads are brought in a distance at least equal to the radius of the counter to prevent field distortion at the counter ends. The Kovar seals have guard rings to prevent high-voltage leakage from the center electrode to the cathode. A 30-mil beryl-

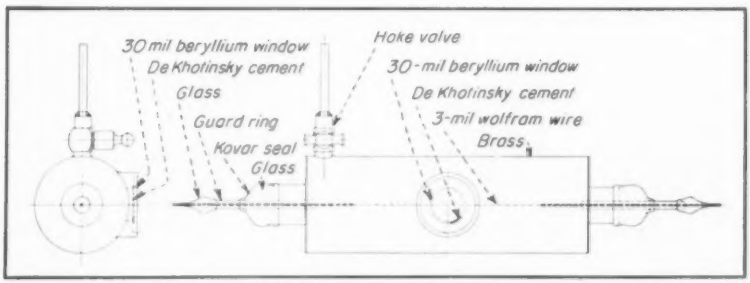

FIG. 1. Proportional counter

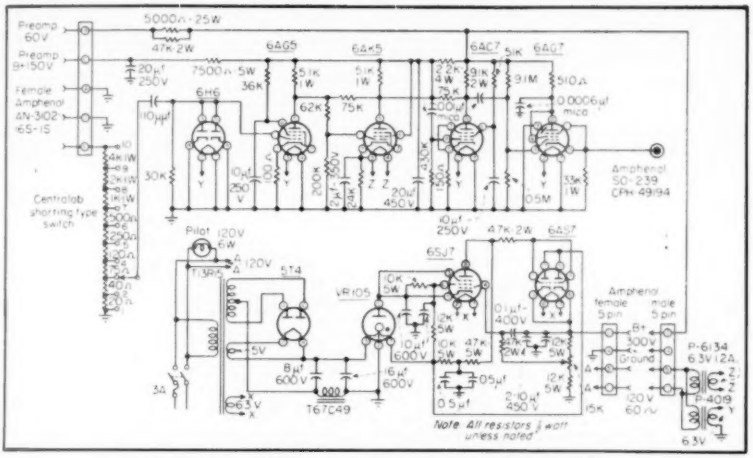

FIG. 2. Circuit diagram of the non-overloading amplifier

lium window is mounted in the side of the counter to admit X-rays into the sensitive volume. Insulators are eliminated from the counting region to prevent charge accumulation and the consequent distortion of the field. A glass counter with an aquadag cathode has also been used. In this case, a long leakage path is provided between the two electrodes, instead of guard rings; no spurious counts have been found.

The counters are filled to atmospheric pressure with 90% neon, argon or krypton and 10% methane mixtures. The counter and preamplifier are mounted together in a metal box to provide electrostatic shielding and to remove need for a cable between them.

The preamplifier is a Los Alamos Model 100 type modified to use 408A tubes instead of 6AK5s. The low filament current drain of the 408As permits their operation from a regulated d-c supply. Also, a 100,000-ohm load resistor is used for the counter to prevent pile-up of the pulses at high counting rates, and a consequent overloading of the preamplifier. The output stage is a cathode follower. The measured gain of the preamplifier for simulated counter pulses is about 80.

Circuits

Figure 2 is a circuit diagram of the amplifier. The essential feature is that it can handle a pulse-height ratio of 7,000 to 1 without overloading on large pulses. The input 6H6 diode is used to clip positive overshoots arising from the initial differentiation of the signal in the preamplifier. A 3 μsec differentiating time constant is used ahead of the clipping diode to reduce the clipping time and permit operation at high counting rates. All other stages which can be overloaded, stages receiving a large positive signal and drawing grid current, are direct coupled.

Plate-to-plate feedback is used over three stages to provide some gain stability. However, it is insufficient to compensate for changes in line voltage if the amplifier filament supply is not regulated. It is necessary, therefore, to operate the instrument on a line-regulating transformer. Under these

conditions, the drift in gain is less than 2% in ten hours. A stepwise gain control is located at the input, which varies the gain in steps of approximately two. Since precision resistors are not used, the gain in each position must be calibrated. The amplifier output stage is a cathode follower. The low-voltage supply is a 300-volt regulated d-c supply and provides the filament voltage for the preamplifier.

The measured gain of the preamplifier and amplifier is 45,000 at the zero attenuator setting for simulated counter pulses. Under these conditions, the input tube noise is about 50 μvolts. Since the preamplifier has no anti-overload features, the operating gas amplification factor is limited by the point at which the preamplifier overloads.

The high-voltage supply consists of 300-volt batteries connected in series to give the desired voltage. Regulated high-voltage supplies are unsatisfactory because of excessive drift.

The counters may be operated with either a positive or negative high-voltage supply. At voltages below 2,500 volts, no difficulty has been encountered with the Centralab 100 $\mu\mu$f, 10 kv, ceramic blocking capacitors, and a positive supply is more convenient in practice. The grounded cathode permits a much simpler shielding arrangement, and provides a safer method for sample changing. At higher voltages, leakage across capacitor surfaces may necessitate the use of a negative supply in order to eliminate the capacitors. The high-voltage filter capacitors are 0.01 μf Glassmikes coated with ceresin wax to eliminate surface leakage.

The pulse-height analyzer is of the single, sliding, channel type described by W. C. Elmore (4). The use of an analyzer of this type requires long-term stability of the counter, amplifier and high voltage, since average determinations require about three hours. The instrument consists basically of two pulse-amplitude discriminators set at the desired channel width apart by a battery. The channel width can be varied from 1½ to 7 volts in 1½-volt steps. The outputs of the two discriminators are connected in anti-coincidence so that only a pulse falling in the channel is counted. A total count discrimination is also included for monitoring purposes or for the measurement of total activity. Both the channel and total count outputs are connected to external scalers and registers. In practice, a channel width of 1½ volts is used to observe the detail of the spectrum.

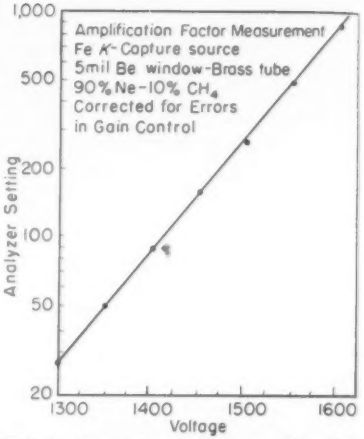

FIG. 3. Dependence of the amplification factor on high voltage

The counters are operated between 1,500 and 2,100 volts, depending upon the counter filling. The amplification factor is about 10^3 although they have been operated as high as 10^5. At higher amplification factors the preamplifier is overloaded and the results are meaningless. Figure 3 is a plot of the pulse height versus the applied voltage for a 5.87 kev X-ray source, indicating that the amplification factor

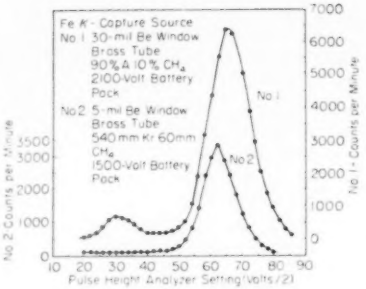

FIG. 4. Spectra of Fe^{55}

is an exponential function of the voltage in the operating range.

Curve 1 in Fig. 4 is a plot of the X-ray spectrum of the Fe^{55} *K*-capture isotope, emitting 5.86 kev Mn X-rays, counted in a brass counter filled with the argon-methane mixture. The width of the main peak at the half intensity point is 20%. Spectra wider than 25% for monochromatic sources are usually caused by air leaking into the counter. A low-energy peak occurs at 2.7 kev, which is 3.1 kev below the main peak. Curve 2 in Fig. 4 is a plot of the spectrum of the same source counted in a brass counter filled with the krypton-methane mixture. In this case, the 2.7 kev peak is absent and only the 5.86 kev peak is present.

Figure 5 is a plot of the spectrum of the Ba^{135} *K*-capture isotope, emitting Cs X-rays of 31 kev, determined in counters of different wall materials and filled with different gases. Curve 1 is the spectrum counted in a brass counter filled with the krypton-methane mixture. The main peak occurs at 31 kev, a larger peak at 17.4 kev, and smaller low-energy peaks at 4 kev and 8 kev. Curve 2 is the spectrum counted in a brass counter filled with the argon-methane mixture. The 31-kev, 8-kev and 4-kev peaks are again present, but the 17.4-kev peak is absent. Curve 3 is the spectrum counted in a glass counter with an aquadag cathode and filled with the argon-methane mixture. Only the 31-kev and 4-kev peaks are present.

Thus, the spectra depend, in part, upon the counter wall material and fillings. The effects of the counter gas are shown in both Figs. 4 and 5. If the incident X-ray ejects an electron from the *K*-shell of a gas atom, the energy of this electron is the difference between the incident X-ray energy and the binding energy of the *K*-shell. After ejection of the *K*-electron, the subsequent rearrangement of the extra nuclear electrons may result in either emission of a *K* X-ray or production of Auger electrons. If Auger electrons are produced, the counter detects the total ionization caused by the ejected *K*-electron and the Auger electrons. This results in an output pulse amplitude approximately equal to that produced by a simple photoelectric effect in one of the outer shells.

The *K* X-rays that escape from the atom are weakly absorbed in the gas (about 25% for argon) and the remainder escape from the sensitive region of the counter. In this event, only the ionization caused by the

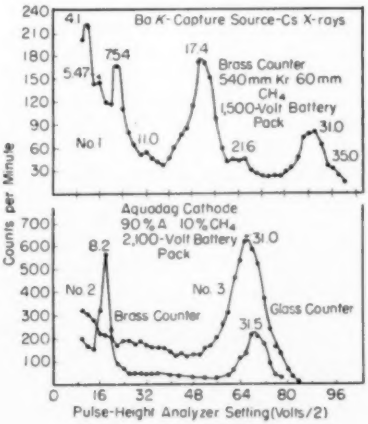

FIG. 5. Spectra of Ba^{135}

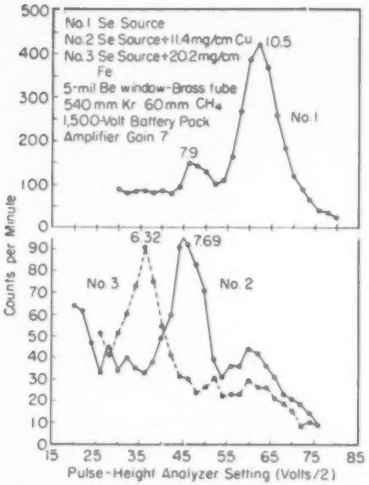

FIG. 6. Spectra of Se^{75} through absorbers

ejected *K*-electron is detected and the output pulse amplitude is decreased by the *K*-shell binding energy. This accounts for the low-energy peak in Curve 1 of Fig. 4, which is 3.1 kev, or the *K*-shell binding energy of argon, less than the main peak. This peak is absent in Curve 2 of Fig. 4 because the incident X-ray energy is not great enough to ionize the *K*-shell of krypton. In Curve 1 of Fig. 5, the energy difference between the 17.4-kev peak and the 31-kev peak corresponds to the *K*-shell binding energy of krypton.

The peak is absent in both argon-filled counters, and the resolution of the instrument has not been great enough to detect the argon contribution. It is, therefore, possible to calculate the efficiency of Auger electron production from the intensity ratios of the two peaks. The efficiency is much greater in argon than in krypton.

The counter wall introduces spurious effects if the incident X-ray energy is sufficient to ionize the *K* shell of the wall material. The 8-kev peaks in Curves 1 and 2 of Fig. 5 are caused by fluorescent radiation from the copper in the wall. The 8 kev peak is absent in the glass counter, Curve 3 of Fig. 5, and the very-low-energy carbon fluorescence has not been investigated.

The 4-kev peaks, Fig. 5, which are present in all curves, are caused by the *L* X-rays from the source. The differences in intensity are caused by the different thicknesses of windows used on the counters and the different absorption coefficients of the gas.

Figure 6 presents further information about the fluorescent radiation effect. These are plots of the spectrum of the Se^{75} *K*-capture isotope (10.5 kev) counted in an argon-methane-filled brass counter, through different absorbers. Curve 1 is taken with no absorber, and the main peak occurs at 10.5 kev with a secondary peak as 8 kev caused by the copper fluorescence. Curve 2 is taken with a copper absorber, and the 10.5-kev peak is greatly depressed with respect to the 8 kev copper peak. Curve 3 is taken with an iron absorber, and the largest peak occurs at 6.32 kev. The fluorescence yield, although small, is easily detected, and must be considered in the interpretation of unknown spectra.

Figure 7 is a plot of the spectra of Mn, Fe, Ni, Cu, Zn and Zr targets

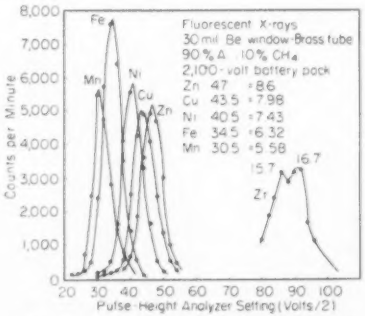

FIG. 7. Spectra of adjacent elements

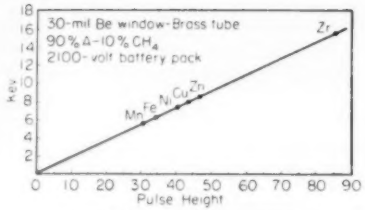

FIG. 8. Linearity curve

excited by an X-ray tube emitting Mo X-rays of about 17 kev. The resolution of the instrument is sufficient to permit the separation and identification of X-rays emitted by adjacent elements. If the zinc spectrum is assumed correct, and the energy of the other X-rays is calculated from it, an error of −200 volts is found in the identification of Mn. This error is due to the long-term instability of the instrument and inaccuracy in drawing the curve.

Figure 8 is a plot of the energy-vs-pulse amplitude for the same elements as in Fig. 7. A straight line through the origin indicates that the linear relationship between pulse height and energy is maintained in the operating range of the instrument. The resolution of the instrument is not great enough at present to distinguish between the *K*-alpha and *K*-beta lines of an element.

The instrument is calibrated with known energy X-rays obtained either from *K*-capture sources or an X-ray tube. Calibration is made frequently, usually before and after a run, to correct for the drift in the instrument. The instrument is also calibrated on all used gain settings to correct for the error in the gain control.

The spectrometer has been used in several types of experiments at Brookhaven National Laboratory, including the identification of unknown X-rays, and in the detection of X-rays emitted by self-ionization of a radioactive nucleus. Further work on the latter problem is in progress.

* * *

The authors are indebted to Dr. Martin Deutsch for his help in developing the equipment, to Dr. J. B. H. Kuper and W. A. Higinbotham for their encouragement and suggestions, and to E. J. Downs for his help in the construction of the instrument. The authors also wish to thank Dr. S. Katcoff for the use of his K-capture sources.

BIBLIOGRAPHY

1. S. C. Curran, A. L. Cockcroft, J. Angus, *Phil. Mag.* **40**:
   I, No. 300, p. 53 (Jan., 1949)
   II, No. 300, p. 53 (Jan., 1949)
   III, No. 304, p. 522 (May, 1949)
   IV, No. 305, p. 631 (June, 1949)
   V, No. 308, p. 929 (Sept., 1949)
2. G. C. Hanna, D. H. W. Kirkwood, B. Pontecorvo, *Phys. Rev.* **75**, 985 (1949)
3. C. J. Borkowski, E. Fairstein, Abstract T10, *Bull. Am. Phys. Soc* **24**, 7 (Nov. 1949)
4. W. C. Elmore, M. Sands, "Electronics: Experimental Techniques," NNES V-1 (McGraw-Hill Book Co., New York, 1949)

Desirable Improvements in Nucleonics Instruments (*Continued from page 33*)

points, it is the user or potential user who is in need of education.

In conclusion, I would like to express the hope that some manufacturers will be moved to produce equipment incorporating really high quality components and designed for really dependable trouble-free service, and that they or others will also give some thought to the problems facing us in connection with the use of the newer types of counters. The provision of better pulse amplifiers, better regulated high voltage supplies and pulse height analyzers—these are all problems that can be fairly put up to the electronics engineer and manufacturer.

Our other main outstanding problem in nuclear instrumentation (provision of much better neutron detectors than those now at hand) is probably one for the nuclear physicist, at this time. END

Calculations for Maximum Permissible Exposure to Thermal Neutrons

Increased availability of sources of thermal neutrons for research purposes has made such calculations as presented here necessary. Using latest recommended range for the value of rep, the author determines maximum permissible neutron flux.

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THE VALUES currently in effect for maximum permissible exposure to thermal neutrons, in terms of the thermal-neutron flux, are based largely upon the pioneer work of Mitchell (*1*). He takes the neutron distribution in the body as an exponential function of depth and makes this the basis for his calculation. Since Mitchell's early work, it has been conjectured that the actual distribution attains a peak at some depth within the body of the order of a mean free path (*2*). Recent experimental work of Capron, Faes, and Tavernier (*3*), not yet available in detail, tends to confirm this conjecture.

The discussion presented here is devoted to calculating the collision density of thermal neutrons as a function of depth. While the significance of these results for determining a permissible flux is noted, this latter phase is along the lines of earlier work, and no critical discussion of the biological assumptions involved is undertaken.

The body is taken as a homogeneous half-space $x \geq 0$ with the composition and cross sections listed in the table on the next page. The case of a monoenergetic beam of thermal neutrons normally incident at $x = 0$ with a flux of 1 neutron/cm²/sec is considered. It is assumed that the neutrons are scattered isotropically in the laboratory system of coordinates, and that they neither gain nor lose energy by scattering.

These assumptions neglect the different chemical constitution of the various organs, but the effect of this different constitution on the distribution should not be too large since the cross sections do not differ markedly and there is, in many cases, a relatively thick outer layer of tissue.

The assumption of an isotropic distribution of neutron velocities may be expected to become increasingly correct as the number of collisions increases, and the motion of the scattering nuclei probably contributes to this.

The assumption of constant energy for the neutron throughout its history amounts to replacing its actual energy by its average energy. The effect of this assumption is difficult to estimate, but since the cross section of H is rather sensitive to small changes in energy, it may not be negligible. For example, a change in neutron energy from 0.025 ev to 0.015 ev increases the cross section of H by 18%.

Under the assumptions noted, the collision density of the neutrons is evidently a function of depth, say $f(x)$. If we define $f_n(x)$ to be the collision density for neutrons undergoing n-th

collisions, we then have

$$f_1(x) = \sigma e^{-\sigma x},$$

$$f_{n+1}(x) = \frac{\sigma_s}{2}\int_0^\infty dy \int_0^{\pi/2} d\theta f_n(y) \tan\theta\, e^{-\sigma|x-y|\sec\theta}$$

$$= \frac{\sigma_s}{2}\int_0^\infty dy\, f_n(y)\, E_1(\sigma|x-y|) \quad (1)$$

where $E_1(u) = \int_1^\infty dt \frac{e^{-ut}}{t}$

Summing on n, we get

$$f(x) = \sigma e^{-\sigma x} + \frac{\sigma_s}{2}\int_0^\infty dy\, E_1(\sigma|x-y|) f(y) \quad (2)$$

We obtain the solution of Eq. 2 by a method which is simple in principle and deserves to be better known. Assuming a trial solution $g(x)$, we form the iterate,

$$g_1(x) = \sigma e^{-\sigma x} + \frac{\sigma_s}{2}\int_0^\infty dy\, E_1(\sigma|x-y|) g(y) \quad (3)$$

Then if $g_1(x) \geqq g(x)$ for all $x \geqq 0$ it follows that $g_1(x) \leqq f(x)$: i.e., that $g_1(x)$ is a lower bound for the solution $f(x)$. Similarly, if a trial function $h(x)$ can be found such that $h(x) \geqq h_1(x)$ for all $x \geqq 0$, then $h_1(x) \geqq f(x)$ for all $x \geqq 0$, and we have an upper bound for the solution f.

By a certain amount of numerical exploration, we narrow the gap between $h(x)$ and $g(x)$ until we achieve the accuracy required of the solution. A rigorous formulation and proof of this rather intuitively obvious principle and certain other remarks of mathematical interest are relegated to an appendix.

In the present case, the best estimates obtained for g and h follow:

$$h(x) = 14.81e^{-0.4502x} - 5.330e^{-2.952x} \quad (4)$$

$$g(x) = 12.29e^{-0.4502x} - 5.140e^{-5.166x} \quad (4a)$$

The maximum difference between $h(x)$ and $g(x)$ is not more than 1.2 and the function

$$R(x) = 13.11e^{-0.4502x} - 5.140e^{-5.66x} \quad (5)$$

is close to the average of $h(x)$ and $g(x)$. Since $R(x)$ cannot deviate from $f(x)$ by more than 5% in the vicinity of the maximum, and this seems sufficiently accurate, we take $R(x)$ as the solution of Eq. 2. The verification that $h(x)$ and $g(x)$ have the properties required to insure that they are upper and lower bounds for f requires a certain amount of rather tedious but elementary numerical work in locating the minima of $h(x) - h_1(x)$ and $g_1(x) - g(x)$. This analysis will not be given here.

The collision density thus has a boundary value $f(0) = 7.973$ and a maximum value at $x = 0.3189$ cm of $f_{max} = f(0.3189) = 10.37$. See graph on the next page.

The number of ergs of energy absorbed per cm³ due to the production of protons from the (n,p) reaction is then given by,

$$P(x) = 7.334 \times 10^{-10} f(x) \quad (6)$$

Composition and Thermal Neutron Cross Section of Principal Elements in Soft Body Tissue

	H	C	N	O	*Total*
% by weight	10.11	12.14	4.02	73.64	99.91
Total cross section (cm^{-1})	2.787	0.0288	0.02052	0.1151	2.952
Scattering cross section (cm^{-1})	2.769	0.0288	0.01819	0.11508	2.931

giving a maximum at $x = 0.3189$ cm of $P_{max} = P(0.3189) = 7.605 \times 10^{-9}$ ergs per cm³. This calculation assumes the proton is absorbed at its place of origin and that its energy is 0.58 Mev (*4*).

The energy absorption due to the gamma rays produced from H absorption is more difficult to calculate. The source density (photons per cm³) is evidently given by

$$G(x) = 6.098 \times 10^{-3} f(x) \quad (7)$$

We assume these are distributed isotropically and have an energy of 2.185 Mev (*5*). If we assume a gamma ray is absorbed whenever it suffers a collision, we obtain for the energy absorption in ergs per cm³

$G_1(x) = 4.910 \times 10^{-10}$

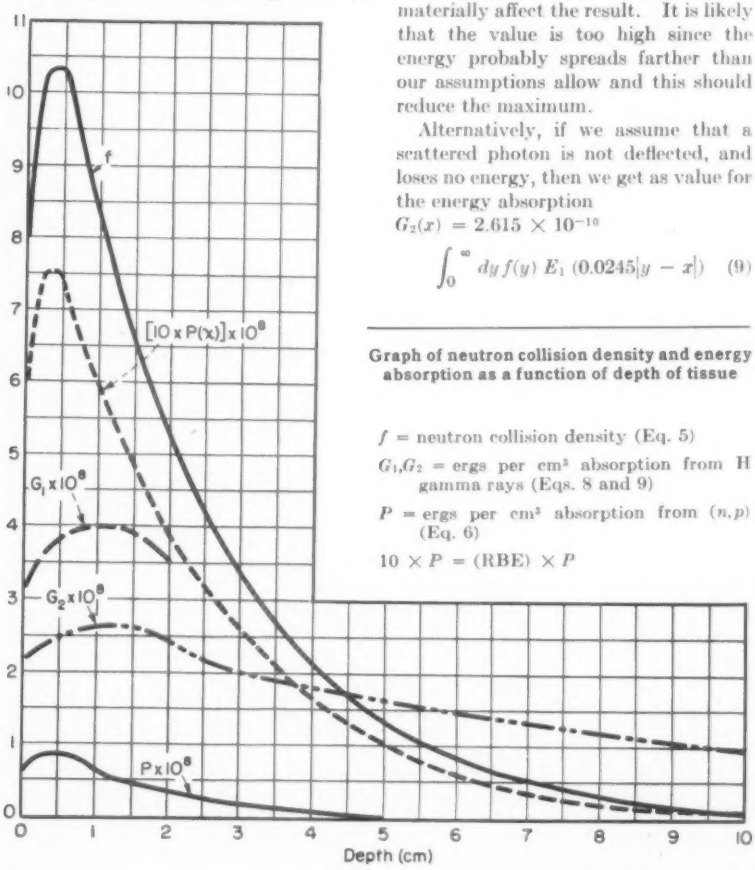
$$\int_0^\infty dy\, f(y)\, E_1\,(0.046|y - x|) \quad (8)$$

The integration yields a curve with a maximum very nearly at $x = 1$ cm. $G_{1max} = G_1(1) = 3.951 \times 10^{-8}$. The mass absorption coefficient has been taken as 0.046 per cm and the extension of the range of integration to ∞ does not materially affect the result. It is likely that the value is too high since the energy probably spreads farther than our assumptions allow and this should reduce the maximum.

Alternatively, if we assume that a scattered photon is not deflected, and loses no energy, then we get as value for the energy absorption

$G_2(x) = 2.615 \times 10^{-10}$

$$\int_0^\infty dy\, f(y)\, E_1\,(0.0245|y - x|) \quad (9)$$



Graph of neutron collision density and energy absorption as a function of depth of tissue

f = neutron collision density (Eq. 5)

G_1, G_2 = ergs per cm³ absorption from H gamma rays (Eqs. 8 and 9)

P = ergs per cm³ absorption from (n,p) (Eq. 6)

$10 \times P$ = (RBE) $\times P$

This calculation yields a maximum absorption very nearly at $x = 1$ cm with $G_{2\max} = G_2(1) = 2.540 \times 10^{-8}$ ergs per cm². This value is probably too low since our assumptions seem to allow the energy to spread farther than seems likely in the actual situation.

In determining the maximum permissible exposure to thermal neutrons in terms of the thermal neutron flux, the following assumptions are made:

1. The relative biological effectiveness (RBE) is 10 for the recoil protons that result from the $N^{14}(n,p)C^{14}$ reaction in tissue.

2. The RBE is 1 for the secondary electrons that result from the $H^1(n,\gamma)D^2$ reaction in tissue.

3. The maximum permissible exposure to the body is 0.06 rem per 8-hour day for a 5-day week. The rem (roentgen-equivalent-man) is that amount of ionizing radiation that produces the same relative biological damage as 1 r.

4. The rep (roentgen-equivalent-physical) as used here is that amount of ionizing radiation that is absorbed in tissue to the extent of 95 ergs per gram of tissue. (The rep was formerly defined as 83.8 ergs per gm of tissue. Representatives of the United States, Canada, and Great Britain at the Chalk River Conference on Radiation Protection meeting at Chalk River, Canada, September 29 and 30, 1949, decided to use a larger value for the rep. The exact value or name of this unit is not determined, but it will probably have a value of between 93 and 100 ergs per gm of tissue.)

Using Eq. 8 for the energy absorption due to gamma rays and 95 ergs per gm as the value of the rep, we get a maximum permissible flux of $N_1 = 1{,}712$. If we use Eq. 9 in place of Eq. 8, we get a second estimate $N_2 = 1{,}951$, and conclude that the critical flux lies somewhere between these limits.

$$1{,}712 < N < 1{,}951.$$

For purpose of comparison, the values obtained if the rep is taken as 83.8 ergs per gm instead of 95 ergs per gm are $1{,}510 < N < 1{,}721$.

BIBLIOGRAPHY

1. J. S. Mitchell, *British J. Radiology* **20,** 79 (1947)
2. R. R. Coveyou, *British J. Radiology* **20,** 260 (1947)
3. P. Capron, M. Faes, G. C. Tavernier, *Nature* **163,** 129 (1949)
4. T. W. Bonner, W. M. Brubaker, *Phys. Rev.* **49,** 223, 778 (1936)
5. M. Wiedenbeck, C. J. Marhoefer, *Phys. Rev.* **67,** 54 (1945)

APPENDIX

Theorem: If the kernel of Eq. 3

$$F(x) = G(x) + \int_a^b dy\, K(x,y)\, F(y) \tag{3}$$

is such that

$$K(x,y) \geqq 0, \qquad a \leqq x,y \leqq b$$

and

$$\int_a^b dy\, K(x,y) < p < 1,$$

where p is a fixed number, then any function $H(x)$ whose iterate $H_1(x) =$

$$G(x) + \int_a^b dy\, K(x,y)\, H(y)$$

satisfies the relation

$$H(x) \leqq H_1(x) \qquad [H(x) \geqq H_1(x)].$$

$a \leqq x \leqq b$ provides a lower bound (upper bound) of the solution F. More

precisely, under the conditions cited, we have

$$H(x) \leqq H_1(x) \leqq F(x) \qquad [H(x) \geqq H_1(x) \geqq F(x)] \qquad a \leqq x \leqq b.$$

Proof: Let M = supremum $[H(x) - F(x)]$ and assume by contradiction that $M > 0$. Then for any $E > 0$, we have $H(x_1) - F(x_1) > M - E$ for some x_1 in the range. Then

$$M - E < H_1(x_1) = \int_a^b dy\ K(x_1,y)[H(y) - F(y)] \leqq M \int_a^b dy\ K(x_1,y) < p\ M.$$

Thus $M < E/(1 - p)$, and this contradicts our assumption $M > 0$. Hence, $M \leqq 0$ and this implies $H(x)$ is a lower bound. The fact that $H_1(x)$ is also a lower bound follows at once from the fact that the property $H(x) \leqq H_1(x)$ is hereditary; i.e., defining $H_2(x)$ as the iterate of $H_1(x)$, we have at once

$$H_2(x) = G(x) + \int_a^b dy\ K(x,y)\ H_1(y) \geqq G(x) + \int_a^b dy\ K(x,y)\ H(y) = H_1.$$

Hence, $H_1(x)$ is also a lower bound of the solution.

It should be pointed out that a lower bound does not always behave in this fashion, so that, in general,

$$H(x) \leqq F(x) \qquad a \leqq x \leqq b$$

does not imply $H(x) \leqq H_1(x)$. Nevertheless, there always exist lower and upper bounds of F which do satisfy the conditions imposed on H and which are arbitrarily close to F. Thus, in principle, a solution to any required degree of accuracy may be obtained by this method. The computational difficulties encountered depend upon the nature of the kernel.

How to Compare Counters

The various characteristics of a counter are important. But the comparison of sample and background measurements—made easy by the equations given here—should be emphasized.

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IN EVALUATING the characteristics of G-M counters, emphasis is too often placed on such desirable features as a long flat counting rate *vs* voltage plateau, freedom from spurious pulses, and a short resolution time. The prime requisite of a good counter, however, is that it should have a high counting rate for the radiation to be measured and a low background. This requirement of sensitivity to the source, obvious as it is, may be overlooked because the problems encountered in the counter discharge mechanism tend to veil its importance.

To realize the highest net counting rate from the source, the outer walls of the counter should be transparent to the radiation and the inner walls or fill gas should be responsive to the radiation. The sample to be measured must be well placed so that the sensitive

counter volume intercepts the greatest possible number of rays. On the other hand, low backgrounds are favored by using the smallest possible counter size, by surrounding the counter with a lead shield to absorb natural γ-radiation, and by using anticoincidence counters and circuits to subtract out effects of cosmic primaries. From the point of view of the counter design, the requirements of low background and of high sensitivity to the source work in opposite directions; also a counter with high sensitivity is also likely to have high background. For accurate measurement of weak samples, the separation of sample counting rate from background is a matter of time-consuming importance.

It is not the purpose of this paper to discuss the design of optimum counters and circuits for various purposes and geometries, but rather to determine from four simple counting-rate measurements which of any two counters being considered is the better. These measurements are the usual sample-and-background and background measurements, taken separately. The measurement must be taken with the desired radiation and from the same source under prescribed geometrical conditions. Except for sample activity, these conditions must be reproduced when the superior counter is placed in service.

Suppose that of two counters considered, counter 2 gives 65% of the net counting rate yielded by reference counter 1. Suppose also that counter 2 has only half the background counting rate of counter 1. Which counter should be used in the application? As will be shown later, counter 1 is the better counter no matter what the sample activity. In other words, the lower background of counter 2 is more than offset by its lower sensitivity; counter 1 should therefore be selected for the application.

In a later example, two experimental counters will be described wherein the lower background of counter 2 more than offsets its lower sensitivity. This lower background counter would be the proper selection for all sample counting rates up to about 20 times the background counting rate.

Consider that the most desirable element in the intercomparison of counters is the saving in counting time. Now, the time expended in taking the background counting rate to good statistical accuracy is very considerable; however, the establishing of the background counting rate can be done on days or nights when the scaling equipment is not needed for anything else. With a good counter, the background rate will have no progressive changes and need be checked only at relatively infrequent intervals. Further, the same background counting-rate measurement with its statistical deviation is used in determining the net counting rate of a large number of samples; hence the time expended in the onerous job of determining an accurate background must be divided among the number of radioassays to which it is applied.

It is in the counting time consumed after the preparation of a specimen where a saving is most desirable. Then the results of the experiment must be known as soon as possible. The next step in the experiment may await the results of an intermediate sampling. Hence, we have picked the sample-and-background counting time T_T as being the element of prime importance.

Let N_T be the number of counts totalized in the sample-and-background measurement and N_B represent the number of counts totalized in the background measurement. The corresponding statistical deviations are $\sqrt{N_T}$ and $\sqrt{N_B}$ respectively. In terms of total and background counting rates these are $(N_T \pm \sqrt{N_T})/T_T$ and $(N_B \pm \sqrt{N_B})/T_B$ where T_T is the sample-and-background counting time and T_B is the

background counting time in the separate measurements of these rates.

The mean net sample counting rate R_s is the mean total rate less the mean background rate:

$$R_s = R_T - R_B \quad (1)$$

For any set of measurements, the statistical deviation in this counting rate must be taken with due regard for the rules for subtraction of statistical quantities, which is given in Eq. 2 as the root-mean-square of the individual deviations of the two statistical processes involved:

$$R_s \pm \delta R_s = \frac{N_T}{T_T} - \frac{N_B}{T_B} \pm \sqrt{\frac{N_T}{T_T^2} + \frac{N_B}{T_B^2}} \quad (2)$$

Note that δ is the fractional deviation in R_s, or, in other words, δ is the desired accuracy of the net sample counting rate. The equations are written in terms of deviation and fractional deviation instead of probable error to avoid repeated use of the coefficient 0.6745. This merely means that there is a 70-30 chance that any single measurement will be within δ times the true mean net counting rate instead of the usual 50-50 chance associated with the concept of probable error.

$$\delta R_s = \sqrt{\frac{N_T}{T_T^2} + \frac{N_B}{T_B^2}} = \sqrt{\frac{R_T}{T_T} + \frac{R_B}{T_B}} = \sqrt{\frac{R_T^2}{N_T} + \frac{R_B^2}{N_B}} \quad (3)$$

Equation 3 is the deviation in net sample counting rate which follows from Eqs. 1 and 2. Since $N_T = R_T T_T$ and $N_B = R_B T_B$, it can be written in any of the three ways shown.

To simplify Eq. 3, either of two assumptions can be made. One is that the time allocated for the sample-and-background measurement is the same as the time allocated for the background measurement. The other assumption is that the number of counts totalized in each measurement is the same. The former results in variable statistical accuracy in the background measurement depending on the sample-and-background measurement. The latter requires a long background counting time. The former is included as Case 1 because it is a common assumption; the latter as Case 2 because the deviation associated with the background measurement is a constant.

CASE 1: $T_T = T_B$

From second form of Eq. 3:

$$T_T = \frac{R_T + R_B}{\delta^2 R_s^2} = \frac{R_s + 2R_B}{\delta^2 R_s^2} \quad (4)$$

To intercompare counter 2 with reference counter 1, the factor of merit M for counter 2 over counter 1 is defined as the ratio of the counting time for counter 1 to the counting time for counter 2 for equal statistical accuracy.

$$M = \frac{T_{T1}}{T_{T2}} = \left(\frac{R_{s1} + 2R_{B1}}{R_{s2} + 2R_{B2}}\right)\left(\frac{R_{s2}}{R_{s1}}\right)^2 \quad (5)$$

High sample activity: $R_s \gg 2R_B$

$$M_f = \frac{R_{s2}}{R_{s1}} \quad (6)$$

Low sample activity: $R_B \gg R_s$

$$M_0 = \left(\frac{R_{s2}}{R_{s1}}\right)^2 \frac{R_{B1}}{R_{B2}} \quad (7)$$

CASE 2: $N_T = N_B$

From third form of Eq. 3:

$$T_T = \frac{R_T^2 + R_B^2}{\delta^2 R_s^2 R_T} = \frac{(R_s + R_B)^2 + R_B^2}{\delta^2 R_s^2 (R_s + R_B)}$$

$$M = \frac{T_{T1}}{T_{T2}} = \left[\frac{(R_{s1} + R_{B1})^2 + R_{B1}^2}{(R_{s2} + R_{B2})^2 + R_{B2}^2}\right] \times \left[\frac{R_{s2} + R_{B2}}{R_{s1} + R_{B1}}\right]\frac{R_{s2}^2}{R_{s1}^2} \quad (8)$$

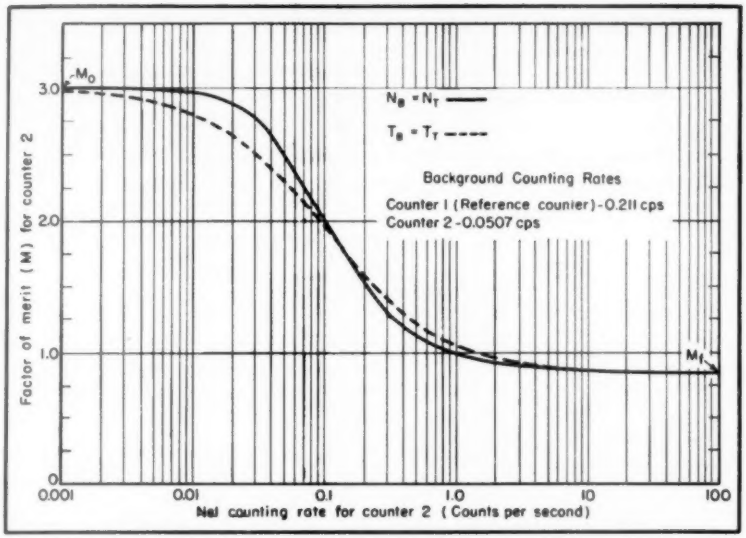
High sample activity: $R_s \gg R_B$

$$M_f = \frac{R_{s2}}{R_{s1}} \quad (9)$$

Low sample activity: $R_B \gg R_s$

$$M_0 = \left(\frac{R_{s2}}{R_{s1}}\right)^2 \frac{R_{B1}}{R_{B2}} \quad (10)$$

The limits represented by high activity where the background can be neglected, and low activity where the background is large, yield the same factors of merit in both cases. Also, if the background counting rates happen to



Factor of merit of a counter as a function of net counting rate

be in the same ratio as the sample counting rates for both counters (*i.e.*, if backgrounds are directly proportional to sensitivity), the factor of merit becomes a constant for all counting rates and equal to R_{s2}/R_{s1}.

Returning to the first example, we may use Eqs. 6, 7, 9, and 10 to illustrate why counter 2, which had 65% of the sensitivity but half of the background, is inferior to counter 1. At high counting rates it is obviously inferior, with a factor of merit of only 0.65. At low counting rates the factor of merit is $(0.65)^2/0.5$ which is also less than one.

Generally, the factor of merit will be a variable depending on the sample counting rates and the backgrounds. However, the net sample activity may be scaled up or down from a single measurement with each counter, so that the factor of merit may be readily computed for all counting rates. The factor of merit is plotted in the accompanying graph as a function of the net counting rate for counter 2. The solid curve is based on Eq. 8 and the dotted curve on Eq. 5. The dotted curve is less realistic in practice since the background counting time is not usually varied.

Counter 2 is an end-construction thin mica window counter of 16 mm diameter. Counter 1 is an end-construction thin mica window counter of 33 mm diameter. A sample of Sr^{90} spread uniformly over a 10 mm diameter area and placed 1.5 mm from the window was used to obtain the data. The measurements were taken with the counters enclosed in 2 in. of lead. Note that for net counting rates up to one count per second, counter 2 is better than counter 1. For net counting rates of 0.01 per second, often encountered in the medical tracer work, the factor of merit for counter 2 is almost 3; that is to say, counter 2 records the net counting rate to the same statistical accuracy in about ⅓ the time that would be required for counter 1. **END**

Engineering Aspects of Nuclear Reactors—III

With each pile usually custom built and with existing security regulations, it is difficult to do more than discuss the engineering design of reactors in a general fashion. Considered here are the construction, assembly, and operation of piles.

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IN THE INTRODUCTION of coolants into the pile, a most significant factor is that the coolant must pass through the reflector and shield. Unless properly baffled or plugged, these openings can permit pile radiation to escape locally. If the cooling ducts serve only to pass the coolant through the shield, they can be arranged spirally or with several offsets as they pass through the shield so as to provide no direct path for the escape of pile radiation. If, on the other hand, the cooling ducts through the radiation shield must be kept straight for any reason, such as the introduction and removal of fuel units through these same openings, then the openings through the shield must be suitably plugged to reduce the local escape of radiation.

Most piles should be arranged so that the nuclear fuel can be removed and replaced as needed. There is a minimum of fuel that must be employed to permit the pile to reach the critical point at which it will begin to sustain a chain reaction. This represents a minimum inventory of fuel in any reactor, and this must be maintained throughout the lifetime of the pile. Only the fuel in excess of this amount can be "burned up" in the production of energy. Even this minimum inventory will change with time as the nuclear fuel units become choked or poisoned with fission products that are neutron absorbers.

In any pile, whether heterogeneous or homogeneous, arrangements must be made to provide for the differential thermal expansion that will inevitably occur, particularly in those piles operating at elevated temperatures. If the differential thermal expansion and, in particular, the unequal differential thermal expansion is not properly cared for, it may interfere with the operation of mechanical devices such as safety or control rods, with the replacement of fuel units, and may even result in the structural failure of the unit. In this respect, homogeneous reactors of the solid type are more subject to this weakness than the heterogeneous-type reactors.

It is impossible in almost any reactor to avoid the problem of differential thermal expansion, even with the most careful design, because of the controls and the cooling. In the most carefully designed pile in which the heat production is nearly uniform throughout the pile, the controls will cause local perturbations while the coolant must inevitably enter at a lower temperature than it emerges from the pile. These differences can never be completely compensated, and every design is a

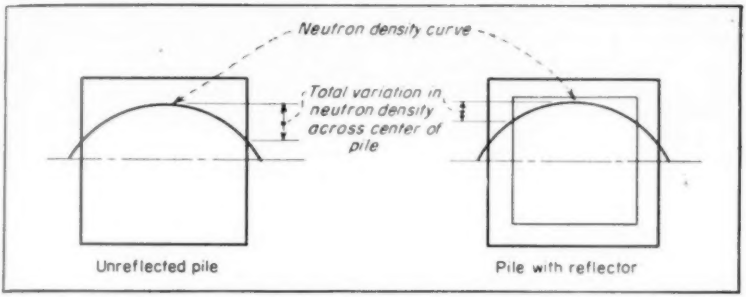

FIG. 1. Variation in neutron density along one axis at center of pile

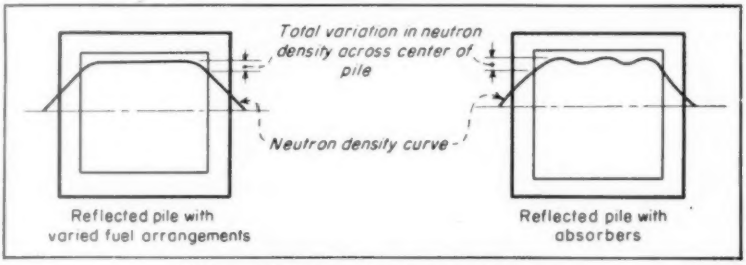
Total variation in neutron density across center of pile
Neutron density curve
Reflected pile with varied fuel arrangements
Reflected pile with absorbers

FIG. 2. Flattening of neutron density curves

compromise among the particular idiosyncrasies involved.

The normal heat production in a pile varies approximately along a cosine curve in the three principal directions, making the heat release a maximum at the center and a minimum at the outer face (Fig. 1). Since this complicates the engineering problems of heat removal and thermal expansion, it is necessary to obtain a more uniform production of heat throughout the reactor. This is achieved by pile "flattening" or a flattening of the neutron density curve across any dimension in the pile (Fig. 2). For example, the addition of a reflector makes the maximum neutron density more nearly that of the average neutron density throughout the pile.

Then, by varying the amount of fuel throughout the reactor, either by varying the spacing or the size of the fuel units, the neutron production throughout the pile can be made more nearly uniform. The same effect can be achieved in the lengthwise position by varying the length of the fuel units throughout the reactor. Another scheme is to introduce absorbers or poisons at strategic points near where the neutron density peaks to depress these peaks and make them more nearly the same as the average value.

In some cases, the rate of cooling can be varied throughout the reactor, with more cooling near the center and less near the surface of the pile. Here, the heat production may vary, but the varying rate of heat pickup will cause a more nearly uniform temperature gradient throughout the reactor.

Even with a neutron density more nearly uniform throughout the pile,

the difference in temperature between the inlet and outlet temperatures of the cooling streams is bound to cause a differential thermal expansion with undesirable thermal gradients. To relieve this situation, the coolant can be introduced at the center of the pile to flow outward toward either end. This is more complicated mechanically, but produces a more isothermal condition. Another scheme is to let the coolant enter the pile near the central or hottest section, flow through the reactor, and return through cooling channels in the outer section of the pile, emerging at the same face at which it entered (Fig. 3).

Homogeneous Reactors

The simplest piles to construct, in general, are the liquid homogeneous reactors in which the fuel and moderator are circulated outside of the pile for cooling. The active section of this type of pile is enclosed in a cylindrical or spherical pressure shell with suitable inlet and outlet connections and provisions for controlling the reactor either in the shell or in the reflector. This type of pile must have a separate reflector because of the intimate mixture of the fuel and the moderator. This reflector may be either liquid or solid if it is outside of the pressure shell around the active section of the pile. If placed inside the pressure shell, it must be solid.

If the reflector is placed inside the shell or if there is no reflector, the pressure shell may be made of any material desired and may be as heavy as need be to withstand any pressures with the control inside the shell. However, if a reflector is to be used outside of this pressure shell, the shell must be made of a material relatively transparent to neutrons so that the efficiency of the reflector will not be impaired by the absorption of too many neutrons in the pressure shell. The control may then be inside the shell or in the reflector.

If stainless steel is used for the pressure shell, its thickness must be very small, while if aluminum or beryllium is used, the thickness may be greater, but the strength will be less. Therefore, this type of pile will be limited to low operating pressures and relatively small sizes, and usually will be restricted to pure research. These, of course, are but added reasons to those given earlier for restricting this type pile to research.

Important in the design of a homogeneous reactor is that the recirculating system for cooling the homogeneous mixture of fuel and moderator must be carefully proportioned so that there will

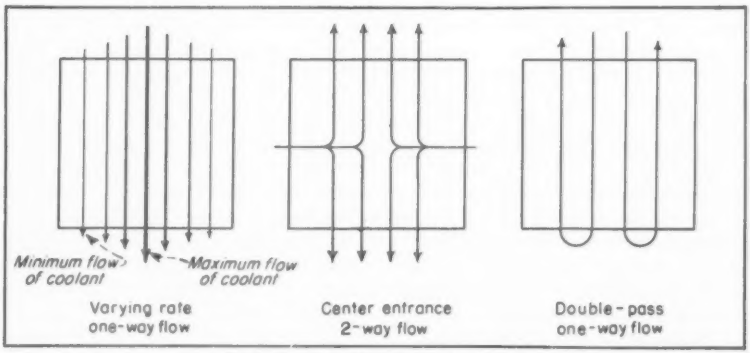

FIG. 3. Variations in cooling flow

be no large volumes of such dimensions as to start a chain reaction outside of the regular pile. Accordingly, the heat exchangers, storage tanks, make-up solution tanks, *etc.*, must all be carefully sized and shaped to avoid this hazard.

This type of pile is relatively easy to assemble because all parts of it, including the reflector, can be completely built before the fuel is inserted into the pile. However, after the pressure shell, reflector, shields, and controls have been assembled, the insertion of the fuel and moderator mixture must be very carefully controlled to make sure that the controls provided are adequate for the safe operation of the reactor. The mixture cannot be immediately circulated through the pile with impunity, but must be introduced slowly until the pile has reached criticality and it has been determined that the rods or other controls are adequate. It may be necessary to change the concentration of the fuel in the mixture before proceeding with the circulation and continuous operation of the pile.

If the large inventory of nuclear fuel required by the above arrangement is objectionable, it is possible to construct a homogeneous reactor with a chamber in which the fuel and moderator mixture remain static while the energy released in the pile is carried away by a separate coolant. This coolant would have to flow through separate channels, piercing the reactor shell much like the conventional heat exchanger. However, achieving and maintaining liquid-tight joints at the seal between these cooling channels and the pressure shell would constitute an important mechanical problem because these joints would be unapproachable and impossible to service. The mechanical construction of this type of reactor would thus be more complex, although the final start-up would be the same. Everything would be completely assembled except for the homogeneous mixture of fuel and moderator, and this would be slowly inserted until the pile reached criticality and the adequacy of controls had been checked.

In both of the above types of reactors, it would be advantageous and probably even desirable to have means available for the quick dumping of a large portion or all of the homogeneous mixture in the reactor in cases of emergency.

Homogeneous reactors employing solid moderators are more difficult to assemble than those described above. The easiest method of construction is to employ the homogeneous mixture of fuel and moderator in powdered form so that it may readily be inserted or removed from the pile. However, in this form, it is difficult to achieve a very high density of the mixture, causing the pile to become unnecessarily large. On the other hand, if the mixture is made in solid form, it must be made in numerous small sections and not in one single section the full size of the pile because an uncontrolled chain reaction would begin in the single section before it ever was inserted into the pile structure. The small sections (which may be in the form of blocks or large disks) must be assembled with the greatest of caution in small units so as to avoid disastrous results. To assemble the reactor in this fashion, it is necessary to leave at least a portion of the adjoining components incomplete until after the active core has been completed. All in all, this type is probably the most unpleasant to construct and assemble.

Heterogeneous Piles

In general, heterogeneous piles have one advantage. The fuel units may be as small or as large as is desired but the pile may be so designed that the entire structure can be built without the insertion of any of the nuclear fuel. Accordingly, the moderator and reflector, controls and cooling systems,

can all be put in place before any of the nuclear fuel is ever introduced. The pile might even be tested by electrical heating to simulate pile-produced heat. Fuel can then be inserted in such a way that the pile behavior as it approaches and reaches criticality can be observed and adjusted as minutely as necessary.

There are innumerable combinations and designs of heterogeneous reactors, depending upon the size, shape, and kind of nuclear fuel and moderator, and upon the type of cooling employed. In general, the fuel can be most simply fabricated and utilized in the form of rods or tubes with a coolant floating around or through the fuel unit (Fig. 4).

If the moderator is a liquid, it can readily be circulated as the coolant, or a separate coolant may flow through the moderator in enclosed cooling channels. If the moderator is a solid, the heat in the moderator can be carried away by separate cooling channels or by the same coolant that carries away the heat from the fuel units, either directly or indirectly. Note that in those arrangements in which the moderator is not cooled by direct transfer to the coolant, the moderator runs hotter than in the other cases in which its heat is carried away directly. This introduces problems of thermal expansion and thermal gradients.

General Construction Details

The various shapes and forms of the nuclear fuel have already been discussed (NU, Dec. '49, p. 45). Probably the most common forms in which the fuels are used are as the metal (because it can be worked and machined) and as the oxide or carbide (because it is refractory and more suitable at elevated temperatures).

As the metal, the fuel units can be almost any size, but the remote control required for the handling and reprocessing of the fuel after irradiation in a pile makes small units desirable. On the other hand, the metallic oxides and carbides cannot be fabricated into very complicated or very large units, so that fuel units of these materials must of necessity be relatively small in size and simple in shape.

The coatings for the fuel units have also been discussed earlier (NU, Dec. '49, p. 46). For metallic fuels, the coatings are generally of aluminum or beryllium or one of their alloys; in rare cases, very thin jackets of stainless steel can be employed. High level intermediate or fast piles can use other materials for sheaths, such as wolfram, tantalum, columbium, *etc.* The small fuel units can be independently jacketed in sealed, liquid- and gas-tight coatings properly bonded or drawn down onto the fuel unit and welded shut; or two or more units can be jacketed in a single coating to eliminate some of the coating material at the ends of the units. This makes handling a little more difficult, but saves on fuel.

Refractory fuel units usually need no jackets for corrosion protection but still need some coating to prevent the escape of fission recoils. These fuel units are hard to coat, even with a refractory glaze. Reactors using refractory-type fuels usually have a binary cooling system, as will be described later. Metallic coatings are difficult to bond for good heat transfer, are usually less refractory, and rarely have the same coefficient of thermal expansion as the refractory. Hence, they are not good coatings for refractory fuels.

Solid moderators can rarely be fabricated into single units of full pile size. They must almost always be made in small units that can be assembled and stacked to form the pile. Such piles will thus contain many small units, and there is a mechanical problem of keeping these properly aligned despite the differential thermal expansion This requires some keying or inter-

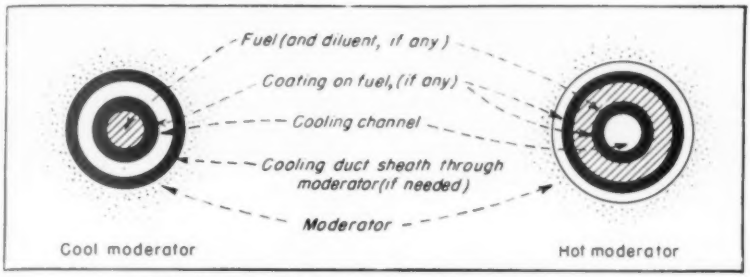

FIG. 4. Typical heterogeneous cooling arrangements

locking of units throughout the pile, particularly near its surface.

The controls are rarely of the types in which part of the reflector, moderator, or fuel is moved or in which the pile is split so that part of the pile moves, because these mechanisms are usually more complicated, more ponderous, too slow in operation because of the size and inertia, and less certain in emergency. These methods all increase the pile power level by insertion of the controlling element and must all be arranged so that the controlling section falls by gravity or is forced by a mechanism *out* of the pile in an emergency, including the failure of the control operating power itself.

Absorbing controls introduced into the pile or reflector are the simpler and more common means of controlling a pile. These may be rods, tubes, balls, or a liquid; in rare cases, a gas might be used for small changes in operating level. All solid absorbing controls, especially the safeties, should be arranged so that they always fall into and not out of the pile in emergencies. This can be accomplished by gravity operation in stationary piles and by mechanical operators in mobile reactors, but must be fixed so that any emergency including a shut-off of the normal control operating power will drive all controls into the pile.

Because these controls pierce part of the pile, the reflector, and usually the radiation shield, they offer an opportunity for local pile radiation to leak out around them unless they fit their holes through the shield rather closely. On the other hand, a close fit in their channels is undesirable mechanically, because any slight warping of the control rod or accidental introduction of a small quantity of foreign material might cause the rod to stick and prevent its insertion into the pile in an emergency. In addition, a close fit means that the sudden insertion of the control may also be prevented by the compressed column of gas in the control channel. Before this gas can escape and let the control rod in, it may be too late.

Therefore, a loose fit for all controls is desirable and must be properly baffled against the escape of radiation. Likewise, the thimble or control channel pocket must be flooded with a nuclearly inert gas so that the sudden insertion of a control will not drive out a stream of radioactive gas into the operating area.

Most absorbing controls are solid but occasionally an absorbing liquid might be used. This should not merely be a solution of an absorbing salt in a liquid, but rather a liquid itself that is absorbing, because some of the soluble salt might deposit on the walls of the control channel and leave

enough absorber permanently in the pile to prevent its further operation.

Gases can be used as controls by varying the pressure on an absorbing gas in the pile. However, this method is usually applicable only to small incremental changes in power level and thus only to fine or regulating controls.

The Shield

Most of the shielding materials and arrangements have already been discussed (NU, Oct. '49, p. 4; Jan. '50, p. 10) but a few other construction details will be mentioned.

Radiation shields depend on the location and purpose of the reactor. For example, a pile might be located under water in a lake or the ocean because the surrounding water serves not only as a super safety control but as a radiation shield.

Liquid shields must be arranged with one or two plenum chambers between the pile proper and the shield so that leaks in the liquid shield tank will be drained away through these plenums and will not contaminate the pile with neutron-absorbing materials. Liquid shields that can become radioactive (like O^{19} formed in water) should have partitions dividing the liquid near the pile from the liquid near the outer face of the shield. This not only prevents radioactive isotopes in the liquid from circulating out near the outer surface of the shield but permits circulating the inner layer of the shielding liquid more rapidly than the outer layer so as to carry away more heat and gases of decomposition.

Solid composite shields should have the boron component concentrated nearer the inner part of the shield to reduce the secondary gamma production, and there should always be a final layer of gamma shielding at the outer surface to stop the last secondary gammas created inside the shield.

While the above construction generalities and details may seem to be more generalities than details in engineering design, this is dictated not only by the security regulations on the details of pile design, but also by the large number of design combinations possible, even with the limited number of materials available for each of the pile components. Every pile will be a custom-built job designed to meet the particular specifications and operating conditions involved in a specific application. Some piles will require special research facilities, even though the reactors are intended for power production, and these will dictate the design of shields and other components. Instead of replacing the fuel units in small mobile power plants, it may be found to be more practical to build the fuel units into the reactor and remove the entire reactor *in toto* for processing, replacing it with an entire new reactor. The handling of the fuel units after removal from a reactor may be performed completely under water or may be in solid coffins according to the exigencies of the operating conditions. There are so many possible combinations and variations that no article could hope to cover all of these or even a small part of them. However, it is hoped that this will at least give the reader an idea of some of the engineering features.

Operation of a Pile

In addition to the paradox whereby the power output capacity of a pile does not depend on the size of the reactor as determined by nuclear considerations, there are a few other seemingly paradoxical characteristics that differ markedly from the conventional power producers with which most engineers are familiar.

For example, when increasing the power output of a conventional power source, the engineer or operator pulls out the throttle to feed more fuel to the

combustion or heat producing component. When the power output is to be reduced, the throttle is inserted farther to cut down the fuel supply. In a nuclear reactor this is not the case, because all the fuel is in the reactor from the beginning. All that the control does is maintain the existing level of power output regardless of what that level may be. Withdrawing the control or throttle from a pile does not establish a new power level but only establishes the rate at which the power level rises. If the control were withdrawn to any point and just left at that point, the power output would not stop at some higher level, but would continue to rise at an ever-increasing or exponential rate until the pile were destroyed as a chain-reacting unit. Hence, the control must be withdrawn only the amount necessary to establish the rate of increase of the pile operating level and must then be replaced to its original position as soon as the desired power level has been reached.

Similarly, the control or throttle must be inserted to establish the rate of decrease in the power level, but must again be withdrawn to its original position when the desired power level has been obtained. As time goes on, the nuclear fuel will be depleted and the pile will be poisoned by the "ash' of the fuel (the fission fragments). Therefore, over a long period of time, this zero setting for the control will change, and the control will gradually be withdrawn from the pile until a point is reached at which the pile is just critical with the controls entirely removed. Beyond this point, the pile will cease to function as a chain reactor and power producer, and will require some purification and/or replacement of the fuel.

There are other factors that influence this zero position of the control mechanism over shorter periods of time, but these can be compensated for either manually by the operators or automatically by suitable control equipment. For example, temperature changes cause corresponding changes in the physical density of the pile materials, and these affect the pile reactivity and hence the control.

A second paradoxical problem in operation, is the residual activity that remains in a pile after it is completely shut down. When conventional power producers are stopped, they dissipate any residual energy in a very brief interval of time so that the unit usually can be completely shut down at a moment's notice. In a nuclear reactor, shutting it down only stops the nuclear chain reaction, but does not prevent the continued release of energy from the residual radioactivity within the pile. Depending upon the operating history of a particular pile (that is, the power level at which it was operated and the length of time it operated at that power level), this residual activity may release a quantity of energy amounting to several percent of the normal output of the pile In many cases, this will be enough to cause serious physical changes in the reactor unless the heat generated is dissipated. Therefore, it may be necessary, in many cases, to continue the cooling operation of a pile after shutdown for a period of time and at a rate that depends upon the past operating history.

The normal controls of a pile may be either manually or automatically operated, but the safety controls must be fully automatic because human hands and brain could not react rapidly enough to prevent what could be a catastrophe. These controls may be actuated by temperature limits, nuclear considerations, coolant failures, power failures, or any other event that would introduce a serious hazard if unchecked.

In the actual operation of a pile, the pile atmosphere can be useful for

detecting coating failures within the pile and rectifying the effects of certain types of accidents. Since the function of the jacketing or coating on nuclear fuel units is to protect the material against corrosion and prevent the escape of radioactive fission products, any failure in a coating, no matter how insignificant, would defeat the purpose of the jacketing and become an aggravating offense. By circulating the pile atmosphere and monitoring it continuously, it would be possible to detect escaping radiation from the failure of a jacket anywhere in the reactor and to identify the approximate location of the offending jacket.

In piles containing an absorbing material such as ordinary water confined to tolerable quantities by channels through the reactor, a failure of the cooling channel would permit large quantities of the absorbing material to permeate the entire pile and affect the chain reaction adversely. By circulating and drying the pile atmosphere, the effects of such accidents can be rectified, within limits.

There is one other major operating problem to be considered here. Eventually, almost any pile ever built will have to have its fuel replaced, depending on its operating cycle and life.

Operating Life

As has been indicated previously, there is a minimum amount of nuclear fuel that will sustain a chain reaction in a specific pile, but there is also a maximum amount of nuclear fuel for this same pile, beyond which it is impossible to control the reactor by any practical means. For the successful safe control of a chain reactor, only a relatively small amount of nuclear fuel can be built into a pile in excess of the minimum inventory required to maintain a condition of criticality. This arises from the fact that control of a pile is achieved only by virtue of the delayed neutrons from the radioactive decay of the fission fragments. These constitute a very small percent of total fission neutrons produced.

The difference between the minimum fuel inventory and the total amount of fuel in the pile represents the usable amount of fuel. Accordingly, a pile normally can only be operated until this small amount of excess fuel is burned up, after which the fuel has to be replenished. The rate at which this quantity is consumed by the chain reaction determines the life of the operating cycle or the length of time the pile may operate before replacement of the fuel is required.

In a low power level reactor, this time might be years, but in a pile operating at a high power level, the rate of consumption may be so high that fuel replacement would be required much too frequently for practical operation. Since the fuel can usually be replaced only when the pile is shut down and not during its operation as a power producer, such a pile would be shut down more than it was operating and, hence, would be totally impractical. To circumvent this difficulty, additional fuel might be built into the pile, over and above the allowable maximum for safe normal control. Here additional absorbing material would have to be built into the pile in such a way that this absorbing material would just nullify or compensate for the additional nuclear fuel without affecting the normal control, and in such a way that the absorber could be removed as desired.

With such an arrangement, when the controllable excess of nuclear fuel had been consumed to the point that fuel replacement would normally be required, the compensating absorber could be removed from the pile just enough to allow a controllable amount of the excess nuclear fuel to become effective. Thereafter, the pile could

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be operated again for one operating cycle until this new controllable excess had been consumed and the process repeated *ad infinitum* until all the compensated extra fuel had been consumed.

Replacing, Reprocessing the Fuel

The replacement fuel units are generally practically harmless so that they may be handled with impunity. However, their insertion into the pile means penetrating the shield and reflector with these units. Therefore, even though the pile has been shut down, the residual radioactivity presents sufficient hazard to require special shielding and handling precautions in the placement of the new fuel units.

The partially depleted and poisoned fuel units that must be removed for reprocessing are so intensely radioactive that they require not only special shielding precautions in removing them from the pile but particular precautions even during the subsequent handling and processing. In some cases, their removal from the pile might be effected by their displacement with the new fuel units. They might be pushed out or released to fall out, depending on the engineering design of the pile, or, in rare cases, might even be dissolved *in situ* and pumped out in solution. Once released from the pile, they must be transported in shielded containers and stored in shielded vessels or in deep water pits.

By storing the irradiated units for a period of time after their removal from a pile and before their reprocessing, at least some of the shorter lived residual activity will be allowed to die out and the total shielding required for the handling and reprocessing equipment thereby reduced.

The nuclear fuel unit is never completely transmuted but always contains some unfissioned fuel. This usually constitutes a relatively large part of the irradiated nuclear fuel; thus it is obvious that it must be reclaimed for subsequent use. This reclamation and the subsequent reworking of the reclaimed material back into usable fuel units thus constitutes a major objective in the reprocessing, because even a slight loss in the efficiency of recovery means an appreciable loss of an important and critical material.

Since many nuclear fuels are carried in diluents that must pass through the reprocessing with the fuel, the reprocessing is complicated by the presence of a large proportion of extraneous material. If the diluent is also a fertile material, then this must not only be separated from the other products, but the new artificial nuclear fuel created in the fertile diluent must be removed also and separated from the diluent.

There are also all the poisonous fission products to be removed from the fuel. These may be in any phase, but generally are either gaseous or solid. The gaseous radioactive fission products must be dissipated by dilution with large quantities of an inert gas and subsequently released from a stack at heights sufficient to obviate any radioactive hazard in the vicinity. The solid radioactive fission fragments may have some value that warrants reclamation but are usually in such small quantities that tracer techniques are required for their separation. Most of these probably have more nuisance value than utility and have to be buried in some safe area to prevent radiation hazards.

The reprocessing of many fuels is complicated by the presence of protective jackets or sheaths that must be dissolved or removed before the fuel unit can be separated into its components. The reprocessing of fuels from homogeneous piles will be still more complicated by the presence of tremendous amounts of moderating material that must be separated from the other components. END

Staff report on:

Conference on Industrial and Safety Problems

NYU, AEC sponsored meeting attracts full house to hear lectures and discussions of immediate significance in the growth of the atomic energy field. Three-day conference held successful and a prelude to others.

THE ATOMIC INDUSTRY may be considered truly "of age" when its conventions and conferences match those of other American industries. Perhaps the nearest approach up to date was the meeting held January 10–12 in the General Electric Auditorium, New York, under the dual sponsorship of New York University and the AEC.

There were nearly one hundred registrants, aside from speakers, from the United States and Canada. The (relatively) high tuition fee ($50) for the meeting served to maintain both the quality of papers delivered and the audience attending formal sessions. Representatives from insurance companies and from the AEC and its contractors formed a majority present, but universities, construction and manufacturing companies and public health departments were also well covered.

On the first day the introductory remarks of John E. Vance, Myron A. Coler and Paul A. McGhee, all of NYU, were followed by an excellent survey of the present status of the AEC in non-military developments by Wilbur E. Kelley, Manager, New York Operations Office, AEC. Once again a ranking official of the Commission publicly stated the AEC's desire that American industry take an increasing role in affairs of the atom. The morning session closed with Serge A. Korff, NYU, "bringing up to a common starting point" the obviously diverse knowledge of registrants about fundamental particles and rays.

In the afternoon, Warren E. Winsche and G. K. Green of Brookhaven National Laboratory described the hazards and difficulties arising in the production and use of radioisotopes and fission products, especially as they concern plant workers. With his usual great clarity, G. Failla, College of Physicians and Surgeons, Columbia University, impressed on his audience the facts of biological variation and its importance in any evaluation of radiation effects. Stress was also put on the fact that injury may become evident only years after exposure; changes in blood count and especially in the skin's appearance are useful (with careful, informed interpretation) in diagnosis.

Much of the second day was devoted to radioisotopes. Paul C. Aebersold, Chief, Isotopes Division, AEC, reviewed his division's program with vigor. Over 10,000 different shipments of isotopes have been made to qualified persons and institutions, but the widespread utilization of radioactive and concentrated stable isotopes is still in its infancy. Charles Rosenblum, Head, Radioactivity Laboratory, Merck & Co., Inc., gave an excellent paper on the use of radioisotopes in industry. Forrest Western, Associate Director, Health Physics Division, Oak Ridge National Laboratory, reviewed general health problems and safety procedures.

In the afternoon of the second day, Thomas Lanahan, S. Blickman, Inc., V. Lawrence Parsegian, Kellex Corp., S. E. Eaton, Arthur D. Little, Inc., and F. C. Henriques, Jr., Tracer-

lab, Inc., speaking more nearly the language of industry, discussed problems involved in the design and operation of a radiochemical laboratory and described experiments that are or may be performed. The *why*, *how*, and *when* questions that arise when choosing procedures were not overlooked.

Commissioner Gordon Dean, AEC, spoke at the dinner session on Wednesday at the New York University Faculty Club, Washington Square. He stressed the fact that new horizons appeared frequently in the "radioactive squirrel cage" of AEC Washington. He doubted the necessity for indefinite continuation of the U. S. monopoly (internal to the U. S.) in the isotope field; but indicated that the turning over of isotopes to industry "lock, stock, and barrel" was something for the far rather than near horizon.

Bernard S. Wolf, Chief Radiologist, Mt. Sinai Hospital, spoke on Thursday morning making the excellent point that medical control programs are relatively simple but, unfortunately, medical evidence of radiation damage to any specific individual is not an early sign of exposure above acceptable levels. Such so-called overexposures can be detected and prevented only by personnel and area monitoring with suitably designed instruments. Abel Wolman and Arthur E. Gorman, Consultant and Sanitary Engineer, AEC, respectively, divided the subject "Waste Materials in the Atomic Energy Program" in a long and excellent paper. The morning session ended with the remarks of J. Dewey Dorsett, Association of Casualty and Surety Companies. One of his strong pleas was for a *complete armament of accurate knowledge* (emphasis supplied), if the casualty insurance industry and every other industry is to face fearlessly and with utmost confidence the atomic era which we are now entering.

Panel discussions based primarily on previously handed-in written questions from registrants closed the three-day conference Thursday afternoon. Technological problems were discussed by Aebersold, Merril Eisenbud, and George C. Manov, AEC, and Lanahan, under the chairmanship of Parsegian. The panel on the impact of atomic energy on insurance and safety consisted of Dan Hayes and Edward Kehoe, AEC, and Reuel C. Stratton and Charles Williams, The Travelers and Liberty Mutual Insurance Companies, respectively, under the chairmanship of S. C. Rothmann. The final discussion centered on "how to do business with the AEC," by William Maher, AEC, H. R. Mayers, General Electric Company, and Nathan Woodruff, AEC, under the chairmanship of Robert Colborn, *Business Week*.

The outstanding fact of the entire conference seems to be that a significant number of companies were sufficiently impressed by what they expected to have their representatives get from it, to pay expenses and tuition fees for their people. Men attended from as far away as California and Alberta, Canada. Several were heard to comment that they *had thought* the fee high; none was heard to complain after the conference ended.

Credit for the major organizational effort goes to Sidney G. Roth, Division of General Education, New York University. Chairmen of the technical sessions were John E. Vance, NYU, Norman R. Beers, NUCLEONICS, Myron Coler, NYU, Lyle B. Borst, Brookhaven National Laboratory, and Frank Maslan, NYU.

It is understood that the papers presented and the discussions that followed will be edited and published in book form by Harper & Bros. Certain of the papers now ready may also appear in early issues of NUCLEONICS. END

Neutron Spectroscopy for Chemical Analysis—II

RESONANCE EFFECTS, TRANSMISSION in the $1/v$ REGION

A summary is given of analytical applications of neutron resonance absorption and scattering, including transmission in the $1/v$ region. Interesting examples are provided to illustrate the application and limitations of the methods.

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IN THE FIRST PAPER (*1*) of this series, a general review was given of the properties of neutrons, the nature of their interactions, and the methods by which their interactions could be measured as a function of their velocity or wavelength. It was shown that the cross sections for neutron interactions could be measured for energies from 0.001 ev to 10,000 ev by use of a mechanical velocity selector, a crystal spectrometer, or a modulated cyclotron. In this region, resonance absorption and scattering occur for a number of elements, particularly for those with mass numbers above 100. The general nature and the shape of the resonance curves were discussed in terms of the Breit-Wigner formula.

To determine the total cross section, σ_t, of an element for neutron interactions as a function of energy, it is only necessary to select the neutron velocity with one of the neutron spectrometers, measure the transmission T of a sample of known thickness l and density ρ, and then calculate the cross section (*1*) by the equation:

$$\sigma_t = \frac{M}{\rho \bar{N} l} \ln \frac{1}{T} = \frac{M}{\mu \bar{N}} \ln \frac{1}{T}$$

Here M is the atomic weight, μ represents grams of sample per cm², and $\bar{N}$ is Avogadro's number. Similar measurements are then made for other velocities. The results are usually plotted as cross sections in barns (1 barn = 1×10^{-24} cm²) against either neutron energy in electron volts or neutron time-of-flight in microseconds per meter.

The curve for tantalum in Fig. 1 is typical of the experimental results (*2*) obtained for many of the elements. As shown in this curve, tantalum has a

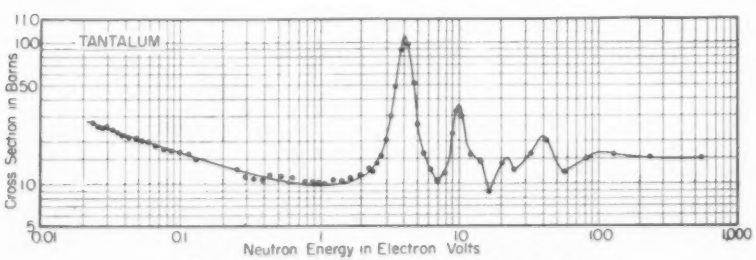
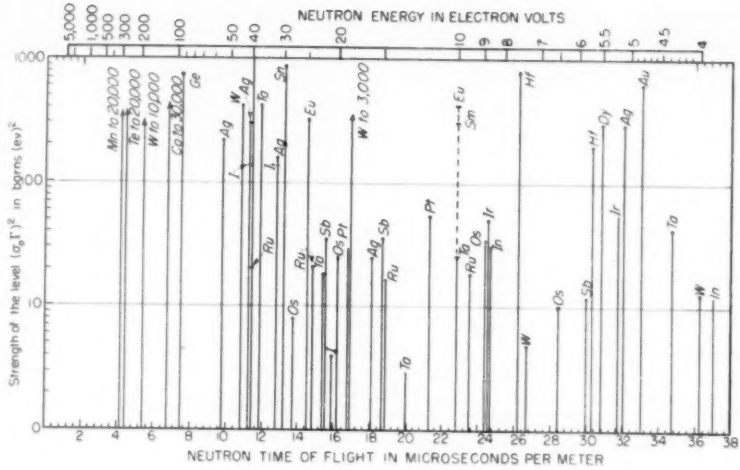


FIG. 1. Slow neutron cross section of tantalum



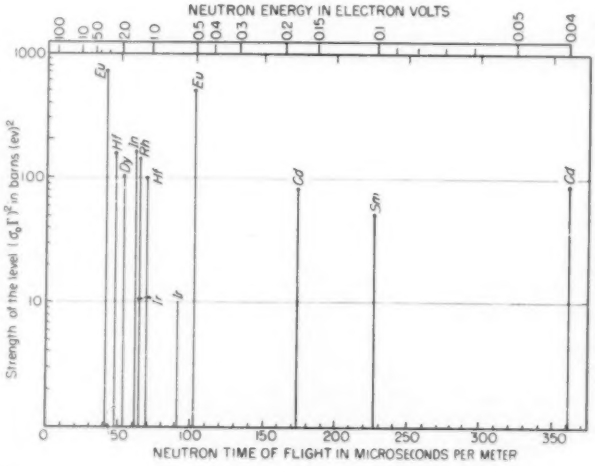


FIG. 2 (above); FIG. 3 (left). Strength of nuclear resonances for the elements

[The heights of the lines are given in terms of the "strength of the resonances" which in most cases are good to a factor of two or better. Those values obtained by methods other than the modulated cyclotron (mostly the rare earths) are probably not as good.]

large resonance absorption at 4.1 ev. This can be used not only to indicate the presence of tantalum but also to measure quantitatively the amount of tantalum in a sample that contains no elements with interfering resonances. It is, for example, useful in determining the per cent of tantalum in a sample of columbium. Similar curves have been obtained (*3*) and compiled (*4*) for many of the elements.

The principal resonances for a number of the elements are given in Figs. 2 and 3. Those elements with large cross sections can be detected qualitatively and determined quantitatively

in the absence of elements with interfering resonances or high cross sections in the region of the resonances. Consequently it is necessary to have some knowledge of the nature of the samples. Resonances for the lighter elements (atomic weights below 100) occur only at relatively high energies where the velocity selectors described previously are not very useful.

Examples of cases where analyses appear to be feasible are:

Tantalum in columbium
Hafnium in zirconium
Indium in tin
Thicknesses of silver, gold, rhodium or cadmium films or electroplate
Manganese in aluminum or iron
Cobalt or manganese in steels
The rare-earth elements, *etc.*

The analysis can be done by obtaining an empirical working curve from a series of appropriate standards just as is done in analysis by light absorption, or it can be done from a single curve, if the Breit-Wigner constants for the resonance curve of the element are known. This is illustrated in the following section by the case of indium impurity present in tin.

Analysis by Resonance Absorption and Scattering of Neutrons

In Fig. 4 the transmission is given for a sample of indium containing 38.65 mg/cm². A section of a similar curve is given in Fig. 5 for a sample of tin 45.15 gm/cm². It is obvious from these curves that the energy of the resonance absorption in the tin sample occurs at 1.44 ev, the same as for the sample of indium. Resonance absorption at this energy is characteristic of the indium nucleus and can be used as a qualitative identification of this element. The following treatment will show how the area of this resonance dip can be used for quantitative estimation,

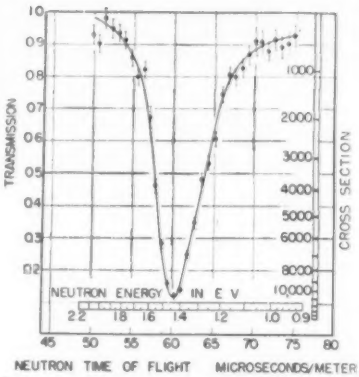


FIG. 4. Slow neutron transmission of 38.65 mg/cm² of indium

once the appropriate constants are known for the element.

Method of analysis. The transmission of a sample consisting of several elements is given by

$$T = e^{-(\Sigma n_i' \sigma_i)}$$

where n_i', the number of atoms of the ith element per cm², is equal to the number of atoms n per cm³ times the thickness l, and where σ_i is the cross section in cm² per atom of the ith element. The energy dependence of σ near a resonance absorption is given by the Breit-Wigner formula (*1*)

$$\sigma = \left(\frac{E_0}{E}\right)^{1/2} \frac{\sigma_0 \Gamma^2}{4(E - E_0) + \Gamma^2}$$

where σ_0 is the cross section of the isotope at resonance; E_0 is the resonant energy; Γ is the half-width of the level in ev at ½ the maximum cross section σ_0; and E is the energy of the incident neutrons in ev.

When the energy of the neutron is not near the resonant energy of any of the isotopes present, the cross section is approximately $4\pi r^2$ [where r is the nuclear radius ($r = 1.5 \times 10^{-13} \times A^{1/3}$, A being the number of particles in the nucleus, *i.e.*, its mass number)]. This

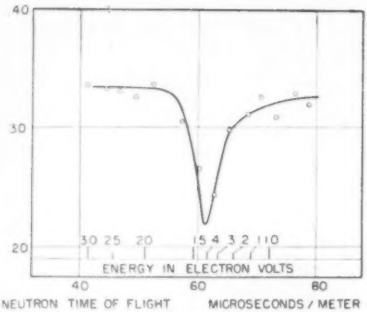


FIG. 5. Slow neutron transmission of 45.15 gm/cm² of tin with a 0.03% indium impurity

cross section varies between 2 and 11 barns for practically all elements. When the energy of the neutron approaches the resonant energy, the cross section increases very rapidly. In some cases, it may become as high as 100,000 barns at E_0. This rapid increase in cross section in the vicinity of a resonance causes the resonant dip in transmission curve.

In the cross section vs energy curve for a sample of material, the observed cross section near a resonance can be divided into two parts: (a) the part that is due to the resonance absorption and scattering of a particular isotope and changes rapidly with energy, and (b) the part that represents the sum of the elastic scattering cross sections of all nonresonant nuclei present and does not vary rapidly with energy. Since one part of the cross section does and the other part does not vary rapidly with the energy, this "background" cross section (the part that does not vary rapidly with energy) can usually be obtained without difficulty.

It is obvious from the transmission curve of tin with the indium impurity that the indium transmission dip recovers to the background transmission of approximately 0.34. The transmission of the sample then remains fairly constant for a relatively wide energy range. A derived "resonance transmission curve" for the indium in this sample of tin can be obtained by dividing the observed transmission curve by the background transmission. This resonance transmission curve is the one used for the quantitative estimation of an element.

Effect of resolution width. To obtain the quantity of an element from its resonance transmission curve, one must consider the method by which the data are obtained.

In the modulated cyclotron velocity selector, as described in the previous article, there is approximately uniform production of neutrons for a time τ and detection of the neutrons for an interval of time τ'. Suppose for simplicity (and usually applied in practice) that we let $\tau = \tau'$. Then neutrons having times-of-flight between $t_1 - \tau$ and $t_1 + \tau$ will be detected and recorded. The probability that the particle having a time-of-flight t between $t_1 - \tau$ and $t_1 + \tau$ being detected will be proportional to the sum of area of the production pulse and the detection pulse overlapping at the time t. Therefore, the probability of a particle of time-of-flight t being detected will be zero at $t = t_1 - \tau$, increase linearly until $t = t_1$, and then decrease linearly to zero at $t = t_1 + \tau$.

The probability of detection can be represented mathematically by a distribution function expressed by the following relations:

$$\Phi(t,\tau) = 0 \quad \text{for } t < (t_1 - \tau)$$

$$\Phi(t,\tau) = \frac{1}{\tau^2}[t - (t_1 - \tau)] \quad \text{for } (t_1 - \tau) < t < t_1$$

$$\Phi(t,\tau) = \frac{1}{\tau^2}[(t_1 + \tau) - t] \quad \text{for } t_1 < t < (t_1 + \tau)$$

$$\Phi(t,\tau) = 0 \quad \text{for } t > t_1 + \tau$$

This distribution function is usually called the resolution function or resolution width of the apparatus. The relation of the resolution function of the apparatus to "cyclotron on time" and "detector on time" is given in Fig. 6.

If the constants for the Breit-Wigner formula are known, a calculated value for the transmission, T_c, of the sample for neutrons of energy E can be obtained from the equation

$$T_c = e^{-n'\sigma_{(E)}}$$

Here n' is the number of atoms per cm² of the absorbing material and $\sigma_{(E)}$ is the cross section of the material at the energy E as given by the Breit-Wigner formula. This, however, is not the curve that is observed experimentally because the apparatus does not have infinitely sharp resolution. To match the experimental curve, it is necessary to include the effect of the resolution width of the apparatus.

The actual observed transmission curve is given by

$$T = \int_{-a}^{+a} \varphi(u) T_c(E + u) du$$

where $\varphi(u)$ is the smearing function representing the resolution width of the apparatus on the energy basis and the a is the half-width of the resolution function.

The observed transmission at a particular energy in the vicinity of a resonance can be quite different from the calculated transmission of the sample at this point. Therefore, the observed transmission value at the minimum of the transmission dip is not a reliable measure of the amount of the resonance absorber.

Area of the resonance dip. The difficulty noted can be circumvented by considering the integrated effect of the level over the energy range where it is effective. Let us define a quantity A which is given by the expression

$$A = \int_{E_1}^{E_2} (1 - T) dE$$

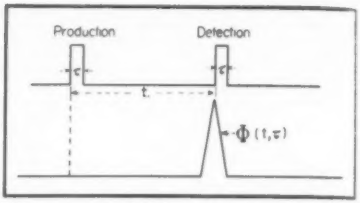


FIG. 6. Resolution function of the apparatus $\Phi(u)$ showing relation to "cyclotron on time" and "detector on time"

where E_1 is less than E_0 and E_2 is greater than E_0. Quantity A represents the area between the observed resonance transmission curve and unity transmission and is proportional to what we shall call the "strength of the resonance level."

Substituting the expression for the experimental transmission into this formula gives

$$A = \int_{E_1}^{E_2} \left[1 - \int_{-a}^{a} \varphi(u) T_c(E+u) du \right] dE$$

Now if: (**1**) $\varphi(u)$ is a symmetrical normalized function, that is,

$$\int_{-a}^{a} \varphi(u) du = 1,$$

(**2**) $(E_2 - E_1) \gg a$, and (**3**) there is negligible difference between the odd derivatives of $T_c(E)$ at the limits of the integration, then the integral may be written as

$$A = \int_{E_1}^{E_2} [1 - T_c(E)] dE$$

Now if we also assume that $E_0 \gg \Gamma$ (as it is in most cases), then the term $(E_0/E)^{1/2}$ is approximately unity over the energy range where σ is very large. The function $[1 - T_c(E)]$ then becomes a function that has a value different from zero in a small energy range compared to the range of integration. Therefore, we can let the limits of the integration go from $-\infty$ to $+\infty$ without changing the value of this integral appreciably.

If we also further simplify the expression for A by changing the variable

E such that $x = [2(E - E_0)]/\Gamma$, the quantity A is given by

$$A = \frac{\Gamma}{2}\int_{-\infty}^{\infty}\left(1 - e^{\frac{-n'\sigma_0}{1+x^2}}\right)dx$$

This integral cannot be evaluated analytically. However, for the two specific cases which are most useful, satisfactory approximations can be made.

If the actual transmission of the sample is very small at exact resonance, that is, if $n\sigma_0 > 1$, then, for values of x sufficiently far from exact resonance that T is appreciably different from zero, the 1 in the denominator of the exponent can be ignored compared to the x^2. This is so because that part of the transmission curve where the transmission is effectively zero (it matters little whether $T = e^{-10}$ or e^{-100}) introduces negligible contribution to the area. We can then write:

$$A_{\text{thick}} = \frac{\Gamma}{2}\int_{-\infty}^{\infty}(1 - e^{\frac{-n'\sigma_0}{x^2}})dx$$

letting $x = 1/z$

$$A = -\frac{\Gamma}{2}\int_{-\infty}^{\infty}\frac{1}{z^2}dz + \frac{\Gamma}{2}\int_{-\infty}^{\infty}\frac{e^{-n'\sigma_0 z^2}}{z^2}dz$$

The first integral is zero; the second integral can be integrated by parts to obtain

$$A_{\text{thick}} = \sqrt{\pi n'\sigma_0\Gamma^2} \quad \text{or} \quad n' = \frac{A^2_{\text{thick}}}{\pi\sigma_0\Gamma^2}$$

Therefore, for a "thick" sample, that is when $n\sigma_0 > 1$, the area between unity transmission and the actual transmission of the sample is directly proportional to the square root of the number of atoms of the resonant nucleus present.

In the case of a "thin" sample, that is when $\sigma_0\Gamma \ll 1$, the exponential can be expanded in a rapidly converging series, and A becomes

$$A_{\text{thin}} = \frac{\Gamma}{2}\int_{-\infty}^{\infty}\frac{n\sigma_0}{1+x^2}dx = \frac{\pi}{2}n\sigma_0\Gamma$$

$$\text{or} \quad n = \frac{2A}{\pi\sigma_0\Gamma}$$

Here the number of atoms in the sample is directly proportional to the area.

If more detail about a certain sample is needed, more terms in the expansion for the thin-sample approximation can be taken. Thus, eight terms in the series gives to within 5% the area for a sample as thick as $n\sigma_0 = 8$. Alternatively, a series of numerical integrations can be performed, and the exact shape of the resonance transmission curve can be obtained. The procedure for fitting the calculated curves to the experimental data has been given previously by Havens and Rainwater (3).

The simple approximations just given are reasonably good, but both of them give too large a value for A/Γ. This leads to too low an estimation for the value of n'. By comparison with the more exact numerical solution to the problem, the error in n' for the approximations can be determined. These values are plotted in Fig. 7.

It can be seen from the curves that, at $n'\sigma_0 = 2$, the corrections for n' for the two approximations are about the same (50%). However, for values of $n'\sigma_0$ of about 0.1 for thin samples and about $n'\sigma_0 = 10$ for thick samples, the deviations are only from 3 to 4%. After the value of n' is determined using the analytical approximations, corrections can then be made from Fig. 7.

Examples of the Method

Application of the resonance absorption method to the specific case of the

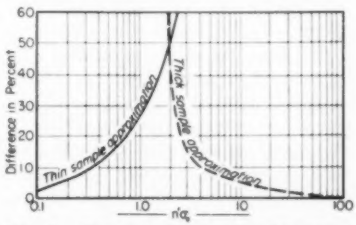


FIG. 7. Correction curves for the approximate area of the derived transmission curve

indium impurity in tin will illustrate the procedure for a typical analysis. In the transmission curve for 45.15 gm/cm² of tin shown in Fig. 5, the constant part of the observed transmission is $T = 0.34$. The actual transmission at each point of the experimental curve is divided by 0.34 and the numbers thus obtained are subtracted from unity. This gives values of

$$\left(1 - \frac{T}{T_{\text{constant}}}\right)$$

which are plotted against the energy in electron volts in Fig. 8 to give the derived resonance curve. The area under this curve was found by numerical integration to be $A = 0.15$ ev.

Since the minimum transmission is a little less than 0.7, the sample is assumed to be "thin" as a first approximation. Substituting the known value of $\sigma_0\Gamma = 2{,}340$ for indium and the experimental value for the area A in the thin-sample formula $n' = (2A)/(\pi\sigma_0\Gamma)$ gives $n' = 4.10 \times 10^{19}$ atoms/cm². Reference to Fig. 8 shows that for $n\sigma_0 = 4.10 \times 10^{19} \times 26{,}000 \times 10^{-24} = 1.07$, the correction for the approximate formula is 29%. The more precise value for n' then becomes 5.19×10^{19} atoms/cm² or 9.9 mg/cm². This corresponds to 0.022% In, with an estimated error of ±0.01% In. This is in reasonably good agreement with the spectographic analysis which showed 0.03 ± 0.01% In. With more precise transmission measurements at the indium resonance, a greater accuracy in determining the area could be achieved.

To be determinable in small amounts by the method noted, the Breit-Wigner constants σ_0 and Γ should be known, and the amount of the element in the neutron beam should be such that $n'\sigma_0$ is not smaller than about 0.2. Otherwise, the transmission at the resonance is too great for good measurements. For indium, this means that a foil containing about 1.5 mg/cm² (0.002 mm thick) can be determined to within 10 to 20%. Similar calculations for gold with $\sigma_0\Gamma^2 = 612$, $\sigma_0 = 24{,}000$ barns, and $\Gamma = 0.16$ show that 2.74 mg/cm² or a thickness of 0.0014 mm is determinable.

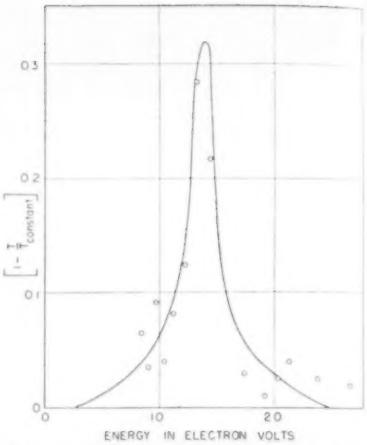


FIG. 8. Derived resonance curve for the indium impurity in tin from Fig. 5

As a further illustration of the requirements of the method, determination of hafnium in zirconium can be considered using the resonance at 7.6 ev where $\sigma_0\Gamma^2 \cong 800$ (Fig. 2). Assuming the resonance to be primarily a resonance absorption, Γ is probably about 0.2 ev, and σ_0 would be about 20,000 barns. For $n'\sigma_0$ equal to about 0.2 (about 80% transmission at the resonance peak), the number of atoms of Hf per cm² required would be 1×10^{19} or about 3 mg/cm².

To determine 0.1% of hafnium in zirconium this would require a sample containing about 3 gm/cm² of the zirconium sample. The modulated cyclotron velocity selector uses a sample about 7 cm in diameter. This means that, as the metal, the sample should be about 5 mm thick or should weigh

about 115 gm. In the range of 1% Hf the sample would be only about 2.5 mm thick and would weigh about 11.5 gm.

Detectability of a Resonance

Actually, the minimum quantity that can be determined depends upon the energy at which the resonance occurs and the constants of the nuclear resonance as shown by the following considerations.

Because the data taken with the modulated cyclotron neutron spectrometer are usually on the time-of-flight basis, the expression given previously for the area of the resonance dip on the energy basis should be converted to the area on a time-of-flight basis. Since $dE/E = 2dt/2$, then

$$A_E \cong \frac{E_0}{t_0} A_t$$

Therefore, $n\sigma_0\Gamma = \frac{4}{\pi}\frac{E_0}{t_0} A_t$ for a thin sample,

and $$\sqrt{n\sigma_0\Gamma^2} = \frac{2}{\sqrt{\pi}}\frac{E_0}{t_0} A_t$$

where A_E and A_t represent the area on the energy and time-of-flight basis, respectively.

Experimentally the criteria for a resonance level is not the area under the resonance dip but the change in transmission at exact resonance. It is difficult to give exact criteria for the strength and energy of the level for a specified transmission because the actual observed minimum transmission depends on the resolution width of the apparatus and the actual nuclear constants of the level. However, we can examine the conditions at the two limiting cases of the resolution width of the apparatus: (1) when the level is completely resolved, and (2) when the resolution width is much wider than the resonance. For these cases the minimum observable number of atoms per cm² can be estimated.

In the case of Cd, the level has been completely resolved with $E_0 = 0.176$, $\Gamma = 0.115$, and $\sigma_0 = 7{,}200$. The minimum transmission will be at the resonance energy E_0 when $T = e^{-n'\sigma_0}$. The maximum ratio of the constant transmission to the resonant transmission that can be observed is about 0.9 or $n'\sigma_0 \cong 0.1$, which gives $n' = 1.39 \times 10^{19}$ or 2.6 mg/cm².

For Mn, where $E_0 = 300$ ev and $\Gamma \sim 5$ ev, with $\sigma_0\Gamma^2 = 20{,}000$, the difference in time-of-flight between the resonant neutron and a neutron of energy $E_0 \pm \Gamma$ corresponds to about 0.03 μsec/m. Since the best resolution width so far obtainable is about 0.9 μsec/m, the observed width of the resonant dip on the time-of-flight basis will be almost completely due to the resolution width of the apparatus. In the case of Mn, if the production interval τ equals the detection interval, the observed transmission dip will be triangular in shape and have a base equal to twice the interval τ. Using the maximum ratio of the constant transmission to the resonant transmission as 0.9, the area will be

$$A_t = [\tfrac{1}{2}][0.9\ \mu\text{sec/m}][1 - 0.9]$$
$$= 0.045\ \mu\text{sec/m}$$

In the case of the thick-sample approximation, the following is obtained:

$$n'\sigma_0\Gamma^2 = \frac{4}{\pi}\frac{E_0^2}{t_0^2} A_t^2 = 15.3$$

so that

$$n' = 7.7 \times 10^{20} \quad \text{or} \quad 71\ \text{mg/cm}^2$$

For Mn, $\sigma_0 \approx 5{,}000$ barns; therefore $n'\sigma_0 \cong 4$, which means the thick-sample approximation is the proper approximation to use.

It should be emphasized that even though the strength of the Mn level is more than 200 times the strength of the Cd level, about 50 times as many Mn atoms as Cd atoms must be present to obtain an observable effect. In the higher-energy region, it is necessary to

TABLE 1
Constants for $E^{-1/2}$ Lines

Element	*a*	*c*
A	0.68	0.123
Ag	6.6	9.05
Al	1.48	0.036
As	4.5	0.68
Au	12.4	14.5
B	3.8	113
Ba	8	0.21
Be	6.1	0.0016
Bi	9.0	0.0023
Br	5.95	1.01
C	4.8	0.0007
Ca	2.5	0.079
Cb	6.4	0.10
Co	6.7	6.4
Cr	4.0	0.56
Cu	7.8	0.54
F	4	0.0016
Fe	11.1	0.34
Ga	7.3	0.35
Ge	8	0.44
He	1.5	0.00013
Hg	15	64
I	3.8	1.12
In	14	64.5
K	1.5	0.4
Kr	27	0.0071
Li	1.5	11.5
Mg	3.5	0.047
Mn	2.26	2.24
Mo	7	0.41
N	9.6	0.48
Na	4	0.071
Nd	14.4	14.6
Ni	17	0.77
O	3.7	< 0.0001
Os	15	2.7
Pb	11.0	0.032
Pd	4.5	0.95
Pt	12	1.03
Rb	12	0.087
Re	5	15.8
Rh	6	23.6
Ru	6.4	0.39
S	1	0.062
Sb	4.2	0.64
Se	13	2.4
Si	2.3	0.032
Sn	4.3	0.088
Ta	7.2	3.2
Te	5	0.63
Tl	9.7	0.6
V	7.7	0.71
W	5.7	2.72
Y	3	0.19
Zn	3.6	0.14
Zr	6.8	0.016

use a relatively thicker sample for detection of a resonance dip.

Analysis by Standards Comparison

In cases where the constants for the nuclear resonance are not known precisely, a comparison method of analysis can be used. In this method, a series of standards is prepared using known amounts of the element in a matrix similar to that of the unknown samples. The area under the derived resonance curve is obtained for each sample. This area is then plotted against the amount of the element present. The curve thus obtained will serve as a calibration curve for this element.

The amount of impurity in a particular matrix may be obtained directly from this curve once the area of the derived resonance curve has been obtained for the unknown sample.

Analysis Using $1/v$ Lines

It was shown previously (*1*) that the cross section at energies below the first resonance and above the region where diffraction effects are appreciable could be given by the formula $\sigma_{(E)} = a + (b/v)$ or $a + cE^{-1/2}$. That is, the cross section is given by a constant scattering term a, plus a term that varies as $1/v$ or as $E^{-1/2}$. Here a, b and c are constants, v is the neutron velocity, and E is the energy in electron volts.

Thus a straight line is obtained when the cross sections in this region are plotted against $1/v$ or against t, the time-of-flight in microseconds per meter. The slope of the line gives the constant b and the intercept gives the constant a. This is illustrated for silver in Fig. 9.

In Table 1 the constants for a number of the elements are listed and a few typical $1/v$ lines are plotted in Fig. 10. The lower limit to the energy where the $1/v$ dependance can be used is the energy region where diffraction effects caused by coherent scattering become

an appreciable part of the total cross section.

For a mixture of two elements having different cross sections at two energies, an estimation of the composition can be made from the cross sections at these energies and from the thickness of the sample. Although the method does not give results as precise as the resonance absorption method, it may find application in special cases.

For elements having considerably different slopes for their $1/v$ lines, the method can be adapted in the following way. The change in intensity dI of the neutron beam with intensity, I_0, as it passes through a thickness dx is:

$$dI = -I_0(n_A\sigma_A + n_B\sigma_B)dx$$

where n_A, n_B, σ_A and σ_B are, respectively, the number of atoms per cm³ and the cross sections of elements A and B. Integration of this equation for thickness x gives:

$$\ln \frac{I}{I_0} = -(n_A\sigma_A + n_B\sigma_B)x = \ln T$$

If the transmission is measured at two velocities v' and v'', where the cross sections are σ_A', σ_B' and σ_A'', σ_B'', the following equations apply:

$$n\sigma_A' + n_B\sigma_B'' = -\frac{\ln T}{x}$$

$$n_A\sigma_A'' + n_B\sigma_B'' = -\frac{\ln T}{x}$$

Consequently, it is only necessary to measure the thickness of the sample and its transmission at two different neutron velocities. These equations can be solved for n_A and n_B, the number of atoms of each element per cc. If the composition is to be expressed in weight per cent, then from the fact that the density d of the sample in gm/cc is given by:

$$d = \frac{n_AM_A}{\bar{N}} + \frac{n_BM_B}{\bar{N}}$$

the per cent of A in the binary mixture is:

$$\% \text{ A} = \frac{n_AM_A \times 100}{n_AM_A + n_BM_B}$$

Here M_A and M_B are the atomic weights of A and B, respectively, and $\bar{N}$ is Avogadro's number.

The determination of manganese in iron will illustrate the requirements of the method. The equations for the cross sections of Mn and Fe in the low-energy region are

$$\sigma_{Fe} = 11.1 + 0.34E^{-\frac{1}{2}}$$

$$\sigma_{Mn} = 2.26 + 2.24E^{-\frac{1}{2}}$$

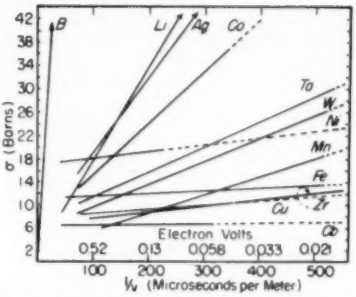


FIG. 10. Typical $1/v$ lines for several elements

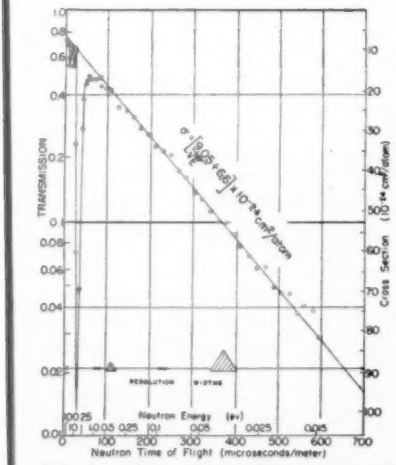


FIG. 9. Slow neutron transmission of 7.84 gm/cm² of silver

At 10 ev, the transmission of a sample 2.0 cm thick was found to be $T' = 0.181$ and at 0.1 ev it was $T'' = 0.136$. The cross sections for Fe at 10 ev and at 0.1 ev are, respectively, 11.2 and 12.2 barns; for Mn they are, respectively, 2.97 and 9.36 barns.

Substitution of these values in the equations above gives

$$11.2n_{Fe} + 2.97n_{Mn} = \frac{1.70}{2} \times 10^{24}$$

$$12.2n_{Fe} + 9.36n_{Mn} = \frac{1.99}{2} \times 10^{24}$$

Solution of these equations gives $n_{Fe} = 7.3 \times 10^{22}$ atoms per cm^3, and $n_{Mn} = 1.13 \times 10^{22}$ atoms per cm^3, or 13.4 mole per cent Mn. This may be converted to weight per cent in the manner described previously.

Assuming that the transmission could be measured to ± 0.01, the error in this particular case might be as high as $\pm 4\%$ Mn. To obtain a greater precision, it would be necessary to measure at energies more widely separated. Other systems such as cobalt in iron, tantalum in columbium, silver in lead, hydrogen content of substances, boron in glass, *etc.*, are more favorable cases since greater differences in cross sections may be obtained at two different energies (see Table 1 and Fig. 10).

If one of the components in the binary mixture is present to a relatively small extent so that it may be classed as an impurity in the principal material, it is more convenient to determine the ratio of the impurity to the principal component in the following way. Taking the log of the ratios of the transmission at the two different energies gives

$$\frac{1}{x} \log \frac{T'}{T''} = n_A(\sigma_A'' - \sigma_A') + n_B(\sigma_B'' - \sigma_B')$$

Assuming B to be an impurity in A, then

$$\frac{n_B}{n_A} = \frac{\log T'/T''}{x n_A(\sigma_B'' - \sigma_B')} - \frac{(\sigma_A'' - \sigma_A')}{(\sigma_B'' - \sigma_B')}$$

The case of an impurity of manganese in aluminum will serve as an illustration. For aluminum, $\sigma_{Al} = 1.48 + 0.036E^{-\frac{1}{2}}$, so that at 10 ev $\sigma_{Al} = 1.49$ barns while at 0.1 ev $\sigma_{Al} = 1.59$ barns. The transmission of a sample of aluminum 20 cm thick (54 gm/cm^2) was found to be 0.164 at 10 ev and 0.135 at 0.1 ev. Substitution in the equation gives

$$\frac{n_B}{n_A} = \frac{0.194}{1.2 \times 10^{24} \times 6.39 \times 10^{-24}} - \frac{0.10}{6.39 \times 10^{-24}}$$

$$= \frac{0.164 - 0.10}{6.39} = 0.010$$

That is, the mole per cent of the Mn in the aluminum sample is 1%. Here again, an examination of the precision to which the measurements are usually made shows that the error may be as high as ± 0.5 mole per cent Mn. A similar examination of this method shows that 1% of tantalum could be determined in columbium to $\pm 0.2\%$ tantalum. Consequently for more precise measurements of small amounts of substances by this method, elements with higher values of σ (Table 1) should be the cases chosen.

A possible application of this method would be in the continuous measurement of the composition of an alloy or other binary system. It would not be difficult to measure the thickness of the sample continuously. In the case of solutions, the cell through which the solution flowed would be of constant thickness. The transmission at two different velocities could then be made by use of one of the velocity selectors previously described or by use of appropriate absorber and detector systems.

For materials that have appreciably different cross sections at two neutron energies, the procedure described here can readily be adapted to the meas-

urement of thickness rather than composition.

Analysis by Transmission Measurements at One Velocity

As will be discussed in the next paper to be published in this series, analyses for elements of high cross sections can be made by simple neutron transmission measurements of a beam of thermal neutrons. However, cases may arise where interferences can be minimized if the measurements are made with a narrow energy band rather than with a broad energy distribution in a beam of thermal neutrons. In such cases, one of the neutron spectrometers, or the appropriate system of neutron filters, would be useful.

The case of a binary mixture in which one of the elements has a relatively high cross section will illustrate the procedure. In this case, it is necessary to know both the thickness and the density of the sample to give the total grams of material per cm². For such a mixture

$$-\ln T = (n_A'\sigma_A' + n_B'\sigma_B)$$

$$= \frac{\mu_A \bar{N}}{M_A}\sigma_A + \frac{\mu_B \bar{N}}{M_B}\sigma_B$$

where n' is the number of atoms per cm²; μ_A and μ_B are the grams per cm² of substances A and B; M_A and M_B are their respective atomic or molecular weights; and $\bar{N}$ is Avogadro's number. Since the total grams per cm² of the sample is $G = \mu_A + \mu_B$, then $\mu_B = G - \mu_A$. Substitution in the equation above gives

$$-\ln T = \mu_A \frac{\bar{N}}{M_A}\sigma_A + (G - \mu_A)\frac{\bar{N}}{M_B}\sigma_B$$

$$= \mu_A K_A + (G - \mu_A)K_B$$

where $K_A = \bar{N}\sigma_A/M_A$ and $K_B = \bar{N}\sigma_B/M_B$. Since T, G and the constants K_A and K_B are known, μ_A may be calculated. Then:

$$\% \text{ A} = \frac{\mu_A}{G} \times 100$$

In some cases, the cross section of one element is so large as compared to the cross sections of the other elements in the mixture that only its contribution need be considered. This would be true, for example, in the case of alloys containing cadmium along with lead, bismuth, or tin. Determining the thickness of electroplated films of such elements as gold, silver, rhodium, *etc.*, on a base material of low cross section also lends itself to this procedure.

The next article to appear in this series in NUCLEONICS will discuss analytical determinations using transmission measurements with beams of thermal neutrons, the decrease in neutron flux by neutron absorbers, and neutron activation.

* * *

The assistance of Mr. Robert A. Anderson, who is studying in these laboratories specific applications of neutron interaction to problems in chemical analysis, is gratefully acknowledged, as is that of Mr. Philip Bendt for determining the relationship between the area of the derived resonance absorption curve and $n'\sigma_0$ by numerical integration.

Thanks are due the Atomic Energy Commission for partial support of this work.

BIBLIOGRAPHY

1. T. I. Taylor, W. W. Havens, Jr., NUCLEONICS **5**, No. 6, 4 (1949)
2. W. W. Havens, Jr., C. S. Wu, L. J. Rainwater, C. L. Meaker, *Phys. Rev.* **71**, 165 (1947)
3. C. P. Baker, R. F. Bacher, *Phys. Rev.* **59**, 332 (1941)
   L. J. Rainwater, W. W. Havens, Jr., *Phys. Rev.* **70**, 136 (1946)
   W. W. Havens, Jr., L. J. Rainwater, *Phys. Rev.* **70**, 154 (1946)
   L. J. Rainwater, W. W. Havens, Jr., C. S. Wu, J. R. Dunning, *Phys. Rev.* **71**, 65 (1947).
   W. W. Havens, Jr., C. S. Wu, L. J. Rainwater, C. L. Meaker, *Phys. Rev.* **71**, 165 (1947)
   C. S. Wu, L. J. Rainwater, W. W. Havens, Jr., *Phys. Rev.* **71**, 174 (1947)
   L. J. Rainwater, W. W. Havens, Jr., J. R. Dunning, C. S. Wu, *Phys. Rev.* **73**, 733 (1948)
   W. W. Havens, Jr., L. J. Rainwater, C. S. Wu, J. R. Dunning, *Phys. Rev.* **73**, 963 (1948)
4. H. H. Goldsmith, H. W. Ibser, R. T. Feld, *Revs. Mod. Phys* **19**, 259 (1947)
   C. Goodman, *et al.*, "The Science and Engineering of Nuclear Power" (Addison-Wesley Press, Inc., Cambridge, Mass. 1947)

CROSS SECTIONS

A Sensitive Directional Gamma-ray Detector*

By Benedict Cassen, Lawrence Curtis and Clifton W. Reed
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As is well known, many attempts have been made to increase the sensitivity of Geiger counter tubes to gamma rays. Special tubes have been made with heavy metal inserts, producing some increase in sensitivity. Others have been constructed with a multiplicity of heavy metal electrodes. Essentially, these tubes consist of a number of counters connected in parallel in one envelope. If the gamma quantum does not produce a recoil or photoelectron from the first electrode, it has a chance of producing one further along its path. These tubes tend to become large and to have a high background unless complicated bulky shielding and auxiliary anticoincidence counters are used.

Two gamma emitters, radioiodine and radiosodium, have been used on a relatively large scale as biological tracers in research and clinical testing. Over-all thyroid uptake of radioiodine is usually measured by a shielded Geiger counter placed in proximity to the thyroid gland. At customary tracer dosages, the total count is small. Any attempt to collimate the counter so that the active region of the thyroid could be partially delineated leads to counting problems involving questions of statistical significance. Obviously, if the counter could be made considerably more sensitive without too much complexity, much more information, such as area and location of the uptake region and possibly the existence of islands where uptake does not occur, could be obtained.

In the use of radiosodium in circulation studies, arrival times at the heart or other parts of the circulatory system are measured after injection. Here again, if greater sensitivity were available, more accurate and detailed arrival regions could be delineated and smaller dosages could be used. Other applications of sensitive directional gamma counters readily suggest themselves.

Several attempts have been made by us to develop more sensitive directional counters. Some schemes gave higher sensitivity but not enough for practical application. The availability of clear calcium tungstate crystals suggested their use in this problem. These crystals have a relatively high density of 6 and a high content of the higher atomic number element wolfram. This makes it possible for them to absorb a high percentage of the incident radiation in a small volume. The scintillations produced by recoil or photoelectrons were observed by means of a photomultiplier tube.

It was questionable at first whether a photomultiplier tube could be used satisfactorily at room temperature because the tube noise would have

* This paper is based on work performed under Contract No. At-04-1-GEN-12 between the Atomic Energy Commission and the University of California at Los Angeles.

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to be biased out to keep the background down, and the scintillation efficiency of the crystals was not known. On actual test we were agreeably surprised with the high brightness of a significant fraction of the scintillations. The signal-to-noise ratio was adequate to enable the noise to be biased to a negligible background.

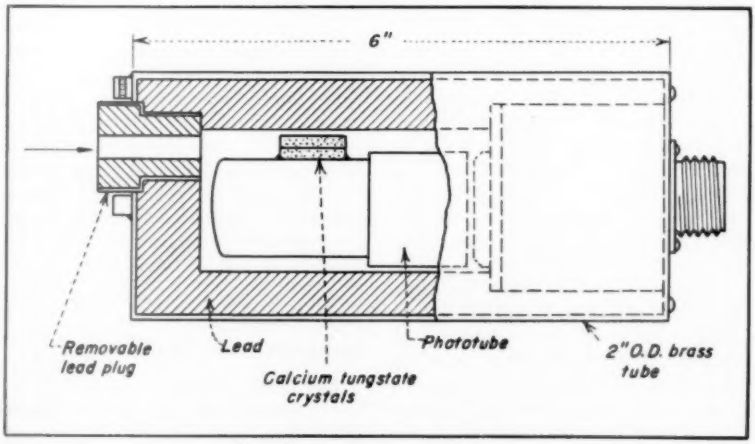
Description of Apparatus

The diagram shows a longitudinal section of the directional counter head developed especially for use with I^{131}. The sensitive scintillating element consists of four pieces of ⅛-in. square by ¾-in. long polished rods of calcium tungstate cemented together with Canada balsam and in turn cemented onto the glass envelope of the photomultiplier opposite the lower two thirds of the photocathode window. The whole glass envelope of the photomultiplier with the crystals cemented on is then wrapped with shiny aluminum foil. The lead housing shown around the tube is adequate shielding for radioiodine but not for radium or radiosodium gamma rays. For the latter emitters, a much heavier and more cumbersome housing is required.

This particular housing design is for locating an emitting region, such as a thyroid gland or other easily accessible regions where, in general, it would be possible to get the entrance port only a centimeter or two from the emitting region. Entrance ports of various sizes can be used to provide various degrees of resolution of the radioiodine distribution to be obtained.

The most noteworthy feature of the electrical circuits (which will be described in detail in a forthcoming report) is that the scintillation pulse from the photomultiplier is taken through a coupling capacitor to an amplifier which feeds to a gated counter. The use of the coupling capacitor enables the photomultiplier to be operated with negative ground, which is conducive to less noisy operation.

The outside of the head is a brass tube which can be hand held or clamped to a counterbalanced arm. The latter procedure is preferable where scanning is to be used. Ultimately it might be desirable to have an



Directional gamma-ray detector

automatic scanning motion and automatic recording. These features have not as yet been embodied.

Sensitivity Test

Radioiodine-131 emits an 0.37 Mev and an 0.08 Mev gamma ray. The first test performed was to determine whether the 0.08 Mev quanta were producing observable scintillations above the bias level. For this purpose, counts were compared with no filter and with a 1.5-mm Cu filter. The half-layer thickness of copper for the 0.08 Mev radiation is about 1 mm; therefore, the filter absorbed more than half of the 0.08-Mev gamma ray. No appreciable difference in counting rates was observable. It was concluded that all the scintillations appreciably above the noise level were due to recoil or photoelectrons from the 0.37-Mev component.

The bias was adjusted so that the noise background count was about two per second. A solution containing effectively 27 μc of radioiodine was placed in a small flat-bottom bottle which was placed directly over the ¼-in. diameter aperture. The amount of radioiodine that could "see" the crystal was calculated to be 5.4 μc. This amount emits 7×10^5 of the 0.37-Mev quanta per second, only a small fraction of which reaches the crystal assembly. With the geometry used, this fraction was calculated to be 1.65×10^{-3}. Therefore, there are 330 hard quanta per second striking the crystal assembly. The sample under these conditions gave a count of about 87 per second, the net count being 85 per second. This indicates that $^{85}/_{330}$ or 25.8% of the hard quanta striking the crystal gave bright enough scintillations to be recorded over the bias setting. This percentage could be increased slightly by lowering the bias to give a higher background count.

No doubt it could be increased considerably by more efficient optical design so that weaker scintillations would better surmount the noise. However, the efficiency obtained for the hard quanta is high compared with that of Geiger counters.

The data obtained indicate that it would be possible to detect 1.5 μc of radioiodine per sq cm at about twice background using the ¼-in. diameter port. Even less than twice background would be statistically significant because several thousand counts could be obtained in a reasonable length of time. The projected area of a normal human thyroid is about 12 sq cm. A total uptake of about 20 μc per gland would then enable one to outline the gland with approximately ¼-in. resolution. By sacrificing resolution by using the larger apertures, the sensitivity could be markedly increased.

It should be noted that the counting rate is not sensitive to the distance of an extended emitting surface from the port. As the emitting surface gets further away, the radiation reaching the crystal from a small element of the surface decreases inversely with the square of the distance. The fall-off is compensated by the fact that the area of emitting surface the crystal "sees" through the aperture increases as the square of the distance. This approximate constancy was experimentally observed with the present arrangement. Of course, the spatial resolution is less for the farther surface.

This article covers only the instrumentation development and testing. A program of clinical testing with this instrument will be undertaken.

NBS Develops Neutron Standard

The National Bureau of Standards has developed a primary neutron standard which makes it possible for all laboratories to measure neutron radia-

tion intensities in terms of a common reference value. The standard consists of a solid beryllium sphere, 4 cm in diameter, enclosing at its geometrical center a capsule of radium. The capsule is made of platinum-iridium closely fitted to a gram of radium bromide compressed to maximum density. Neutrons are produced in the beryllium sphere by the action of gamma rays from the radium. Preliminary measurements indicate that the standard emits 1.1 million neutrons per second. The rate of neutron emission will change slowly as the radium decays, but this change is only about 0.04% a year and can be taken into account with sufficient accuracy.

A duplicate standard has been prepared for loan to other research laboratories requiring standardization of their neutron measurements. The standard is now ready for use and any future revision in the neutron emission rate will result in only a small correction to any data based on the present provisional value. If, as has been suggested, the unit of neutron intensity is defined in terms of the new standard, it will then be possible to express measurements from different laboratories in directly comparable units.

Cutting Flat Vacuum Gaskets on a Lathe

By Robert B. Heller
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This note describes a simple method for cutting flat vacuum gaskets (rubber, neoprene, silastic, *etc.*) on a 10-in. lathe without gluing the gasket sheeting on a face plate.

1. Drill and tap a ¼-in. hole through the center of a 4-in. long piece of hexagonal brass 2-in. wide. Fashion a circle of hard wood 1-in. thick with a diameter about 1 in. larger than the maximum outside diameter of vacuum gasket to be cut. Drill a ¼-in. hole through the center of the wood disk. This disk is to be used as the backing for the gasket sheeting.

2. Make a permanent set of circular brass plates of diameters corresponding to O.D.'s and I.D.'s of vacuum gaskets used in the laboratory. The set made here (of 1/16-in. thick brass) range from 3 in. to 9 in. in steps of ¼ in. and were cut out on a lathe by bolting them through a ¼-in. hole to the 4-in. hexagonal holding bar described above.

3. Make a good cutting tool from an ordinary piece of hard tool steel. If more than one gasket is to be cut in a single operation (up to 3 gaskets of ⅛-in. thick sheeting have been successfully cut here) a cutting edge of knife-edge shape is required of length sufficient to cut through all the gaskets. Best results are obtained when the cutting tool is used in the inverted position (sharp edge upward).

4. Cut out (with scissors) a piece of gasket sheeting of proper diameter and drill a ¼-in. hole through the center. Place the circular sheeting on the large hard-wood faceplate with the proper circular brass plate (*i.e.*, the one corresponding to the O.D. of the required gaskets) laid over. Pass a ¼-in. bolt through the sheeting sandwiched between the wood backing and the circular brass plate and bolt the assembly onto the hexagonal holding bar. Here, it is important to note that it is not advisable to bolt the assembly too tightly or the sheeting may be compressed. Since the sharp cutting tool meets little opposition while cutting the sheeting, tightening the ¼-in. bolt by hand with a lock washer under the head will be sufficient.

5. Place the sharp cutting tool perpendicular to the assembly mounted in

the lathe chuck. Best cutting results are obtained at moderately high lathe speeds. Move the cutting tool into the sheeting at the outer edge of the circular brass plate and work the cutting tool through the sheeting into the hard wood. This procedure yields the correct O.D. of the gasket.

6. Replace the first (O.D.) brass plate with a second (I.D.) brass plate (corresponding to the I.D. of the desired gasket). Use the cutting tool as before to cut the inside circumference of the gasket. The resulting gasket is neatly and accurately cut.

This procedure has the following advantages: (1) a set of permanent brass cutting plates can be made up; (2) no glue or adhesive material is necessary; (3) clean accurate gaskets are quickly made up.

Concrete Useful as Shield for Radiocobalt

Concrete can be used as an effective protective barrier for gamma rays from cobalt-60 where space limitations are not too severe, according to the results of an investigation* by R. J. Kennedy, H. O. Wyckoff and W. A. Snyder of the National Bureau of Standards.

Three distinct processes contribute to the attenuation of gamma rays in concrete absorbers: Compton absorption and scattering, photoelectric absorption, and pair production. In each kind of interaction, all or part of the initial energy of the gamma rays is given up to the atoms of the absorbing material, producing secondary photons of lower energy. In the case of Co^{60}, the original gamma rays have an energy of about 1 Mev, so that the only kind of secondary radiation of any importance is produced by Compton scattering. In such scattering, the total measured radiation consists of two parts: the direct gamma radiation which comes from the source as primary radiation, and the remainder which comes from the entire volume of the intervening barrier as secondary radiation.

Low-energy secondary radiation is more readily attenuated by a barrier than is primary radiation. There will thus be a particular absorber thickness for which the rate of production of new secondaries is just balanced by absorption. This equilibrium condition did not appear, however, in the range of shielding thicknesses considered.

Narrow-beam attenuation data was obtained through the use of concrete absorbers in the form of small cylinders about five inches in diameter and six inches long. Absorbers of iron, copper, nickel, and lead were also studied. A lead shield with a conical center hole was used as a diaphragm to form a narrow beam of radiation, giving an irradiated area 2.5 cm in diameter on the absorbing material. A separate experiment was performed to demonstrate that this arrangement really provides narrow-beam conditions. For broad-beam attenuation measurements no diaphragm was used, and the concrete absorbers were made in the form of 5,000-lb slabs, 8 ft by 8 ft by 6 in. The mean density of these concrete blocks was 2.35 gm per cc.

AEC Designs "Student" Counters

A "student-type" Geiger-Müller counter, designed for high school laboratory use, was demonstrated by the New York Operations Office of the AEC at the Federation of Science Teachers convention in New York on December 29. Made entirely of commercially available parts, the four models shown can be built for approximately $40 each.

According to H. LeVine and H.

* *J. Research Natl. Bur. Standards* **44** (Feb., 1950).

DiGiovanni, designers of the instrument, the counter differs from conventional laboratory counters in its novel power supply and G-M tube output circuitry. The device utilizes an interrupter-type power supply fed by two 1½-volt batteries. The pulse voltage from the interrupter relay is passed through a step-up transformer and is converted to direct current by a cold-cathode rectifier tube (or a selenium rectifier stack). The voltage is smoothed by a 0.005 μf high voltage capacitor. This arrangement develops 1,000 volts d-c which is stabilized to within 1% by a corona-discharge voltage regulator to provide steady high voltage for the G-M tube.

The signal output of the G-M tube can be read in three ways:

1. Rate meter circuit—calibrated microammeter is used.
2. Neon flasher integrator circuit—frequency of flashes indicates radioactive source strength.
3. Audio indicator circuit—comparison with the rate of clicks of a standard sample provides rough measure of sample activity.

Instructions for assembling and testing these counter circuits and circuit diagrams are available from U. S. Atomic Commission, N. Y. Operations Office, 70 Columbus Ave., New York 23, N. Y.

Chalk River Conference Recommends Tolerance Values

At the Chalk River, Ontario, conference of the radiation protection committees of the United States, Great Britain and Canada on September 29 and 30, various values for maximum permissible exposures and concentrations were recommended. Dr. Conrad P. Straub, in his recent talk "The Sanitary Engineering Aspects of Radioactive Waste Disposal" (at the AAAS meeting in New York), discussed and presented some of the recommended values, presented in Tables 1 and 2.

TABLE 1
Weekly Tolerance Values

Type of Radiation	*Value per Week*
X—or gamma radiation	0.3 r
Beta	0.3 rep
Alpha	0.015 rep
Fast neutron	0.03 rep
Thermal neutron	0.06 rep

TABLE 2
Permissible Amounts and Concentrations of Radioisotopes that Become Fixed in the Body (As Applied to Plant Personnel)*

Element	*Maximum Permissible Amount in the Body*	*Maximum Permissible Concentration*		
		μc/cc		*mg/liter*† *(in water)*
		Air	*Water*	
C^{14}	30 μc	10^{-6}		1.9×10^{-7}‡
Na^{24}	15 μc	10^{-6}	5×10^{-3}	5.5×10^{-10}
P^{32}	10 μc	2×10^{-8}	2×10^{-4}	6.8×10^{-10}
S^{35}	200 μc	10^{-6}	10^{-2}	2.3×10^{-7}
I^{131}	0.1 μc	10^{-9}	10^{-5}	7.8×10^{-11}
Ra^{226}	0.1 μgm	2×10^{-13}	4×10^{-9}	4×10^{-8}
Sr^{90} Y^{90}	.....	10^{-10}	2×10^{-6}	1.5×10^{-8}

* All values in the table are divided by an additional factor of safety of 100 when they are applied to large centers of population.
† These values were computed by Dr. Straub.
‡ In air.

BOOKS

Engineering Developments in the Gaseous Diffusion Process (Div. II, Vol. 16, of National Nuclear Energy Series), edited by Manson Benedict and Clarke Williams, McGraw-Hill Book Co., Inc., New York, 129 pages, $1.25. *Reviewed by Richard S. Morse, President, National Research Corporation, Cambridge, Massachusetts.*

This book covers, under four sections written by different authors, a variety of unrelated subjects, each of which were of importance to the successful operation of the gaseous diffusion plant at Oak Ridge.

Part I covers the design, construction, and operating characteristics of three extremely useful devices: a recording spectrometer for process gas analysis, a recording ionization chamber, and a magnetic gear for torque transfer. A fairly detailed description of the design and construction of each device is given, together with results obtained under operating conditions in the gas diffusion plant.

Part II describes developments in vacuum engineering which to a large extent resulted from the extremely rigid requirements for tightness of equipment at the K-25 plant. In Chapter 4, complete information is given for the design and operation of the now well-known vacuum leak detector based on the mass spectrometer principle. Jacobs and Zuhr in Chapter 5 review the various problems of leak detection and give recommended procedures and specifications based on the experience at Oak Ridge.

Part III contains only one chapter which involves a detailed discussion of the theory of heat and mass transfer as applied to the design of cold traps used to condense gases to the solid phase. The rate of solid deposit is expressed in terms of gas flow, and various relations, such as composition in the solid phases in terms of heat transfer, *etc.*, are developed.

Chapter 6 includes complete engineering data on the absorption of UF_6 in a nonaqueous system employing oil. A comparison is made with existing data for other systems with lower molecular weight materials, and the problems of correlating such data as available in the chemical engineering literature are discussed.

In Chapter 8 there is a description of the design problems and operating characteristics of a continuous fluorine disposal plant. Operation is based on the use of caustic soda with continuous chemical regeneration to reduce the sodium fluoride concentration.

A two-page but incomplete account of the reaction of fluorine oxide (F_2O) with sodium hydroxide is given in Chapter 9.

Radioactive Tracer Techniques, by G. K. Schweitzer and Ira B. Whitney, D. Van Nostrand Co., Inc., New York, 1949, 241 pages, $3.25. *Reviewed by Robert B. Duffield, Physics Research Laboratory, University of Illinois.*

This book is an elementary laboratory manual for use in a course in radioactive tracer work. It contains detailed procedures for 28 simple experiments illustrating the use of detection apparatus and the application of tracers to chemical problems. Representative titles are: The Lauritsen Electroscope, The Geiger-Müller Counter, Measurement of Radioactive Liquids, Solubility Determinations, Exchange Reactions, *etc.* For each experiment there is a detailed list of the apparatus and radioactive material required.

The first 85 pages (over one-third of the book) are devoted to an unneces-

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sarily extended account of the hazards of working with radioactive material. This subject is treated much more concisely and usefully elsewhere, for example, in a publication of the National Bureau of Standards.

This book will be useful to instructors wishing to set up an elementary course in the use of radioactive tracers. It definitely is not a reference work to be acquired by people doing research in this field.

Electronics: Experimental Techniques (Div. V, Vol. 1, of National Nuclear Energy Series), by W. C. Elmore and M. Sands, McGraw-Hill Book Co., Inc., New York, 1949, 417 pages, $3.75. *Reviewed by William A. Higinbotham, Electronics Division, Brookhaven National Laboratory.*

Electronics is a very broad subject and "Electronics" even when modified by "Experimental Techniques" is an ambitious title. Actually this volume is concerned with "circuitry" for the nuclear research laboratory. The circuits and techniques apply to a much broader field than this, and the treatment is different from any other text with which I am acquainted. It should appeal to all but the most sophisticated electronic engineers.

The volume is not written as a text for students, but rather to describe the circuits used in nuclear research from a practical point of view, with enough theory and detail so that the reader can build and test and, presumably, improve upon them. The arrangement of the material is logical and assumes little of the reader.

The first chapter is a quick review of the ordinary component parts used in circuit construction. It makes no effort to be analytic but emphasizes what to look out for, especially when components are used unconventionally. The second chapter takes up those circuit elements which are the building blocks of most complex circuits—from simple *RC* elements and delay lines through cathode followers, various amplifiers and a variety of trigger circuits. All relevant formulas are included, together with such useful details as, for example, six methods of triggering a multivibrator type of circuit. This chapter is an excellent introduction for the beginner (some theoretical background is useful but not necessary to get a practical understanding of how these things work). And it is especially recommended for those professional electronics engineers who contemplate designing nuclear instruments. The techniques of radar or television are significantly different from those described here.

In the rest of the book the circuit elements are combined to build up most of the complete circuits useful in the nuclear laboratory. The chapter headings show the scope: Voltage Amplifiers, Electronic Counters, Oscillographs and Associated Equipment, Test and Calibration Equipment, Power Supplies and Control Circuits. There are plenty of circuit diagrams with complete information, graphs, charts, and sketches or photographs where the layout is critical. In contrast to many circuit diagrams in periodicals, these are legible and generally laid out logically with signals traveling from left to right, high voltage at the top and so on.

The book was intended not to be complete, but to give enough information so that instruments can be built and used intelligently. The information could hardly have been more compressed. A few minor errors will be found and some of the parts numbers, notably pulse transformers, are now obsolete. One might wish there had been more references.

The field of nuclear instrumentation is rapidly changing but, fortunately, the information is still valid and impor-

tant. The tubes one may use may be different today, but this will be a very useful handbook for the circuit builder for many years to come.

BOOKS RECEIVED

Vacuum Equipment and Techniques (Div. I, Vol. 1, of National Nuclear Energy Series), edited by A. Guthrie and R. K. Wakerling, McGraw-Hill Book Co., Inc., New York, 1949, 264 pages, $2.50.

Characteristics of Electrical Discharges in Magnetic Fields (Div. I, Vol. 5, of National Nuclear Energy Series), edited by A. Guthrie and R. K. Wakerling, McGraw-Hill Book Co., Inc., New York, 1949, 376 pages, $3.50.

Atomic Medicine (Radioactivity in Peace and War), edited by C. F. Behrens, M.D., Capt. MC, Thomas Nelson & Sons, New York, 1949, 416 pages, $7.50.

Theory of Atomic Collisions (Second Edition), by N. F. Mott and H. S. W. Massey, Oxford University Press, New York, 1949, 388 pages, $8.75.

Trilinear Chart of Nuclear Species, by William H. Sullivan, art work by Kay Benscoter, John Wiley & Sons, Inc., New York, Chapman & Hall, Ltd., London, 1949, $2.50.

OTHER LITERATURE

A Guide for Contracting of Construction and Related Engineering Services, U. S. Atomic Energy Commission. Booklet contains information on various types of contracts used by the AEC, including lump-sum, fixed-price, and cost-plus-a-fixed-fee contracts, and described steps firms should take to be considered for types of work where bids cannot be solicited by formal advertising. *Available from Superintendent of Documents, U. S. Govt. Printing Office, Washington 25, D. C., 10 cents.*

Review of Current Research and Directory of Member Institutions (Engineering College Research Council of the American Society for Engineering Education). *Available from F. M. Dawson, Chairman, in care of the College of Engineering, State University of Iowa, Iowa City, Iowa,* $1.75.

United Nations Atomic Energy Commission, Official Records, 4th Year, Special Supplement No. 1. Recommendations of the Atomic Energy Commission for the international control of atomic energy and the prohibition of atomic weapons as approved at the Third Session of the General Assembly. *Available from Columbia University Press, Morningside Heights, New York, 80 cents.*

High-Frequency Voltage Measurement, National Bureau of Standards Circular 481. *Available from Superintendent of Documents, U. S. Govt. Printing Office, Washington 25, D. C., 20 cents.*

REFLECTIONS

DEAR SIR:

I read with great interest Mr. den Hartog's excellent paper on "Speed of Operation of Geiger-Müller Counters" (NUCLEONICS, Sept. 1949, p. 33). I feel, however, that I should comment on his last paragraph, in which he refers to the quench circuit described by Florida, Davey and myself and expresses the view that its applicability is limited, by comparison with previously described circuits.

While agreeing that the circuit has its limitations, I believe that, in practice,

these limitations restrict its usefulness less than do the limitations of other quench circuits. This is supported by the fact that some 300 quench circuits of this type are in use at this establishment and elsewhere in this country.

When we embarked on the design, we decided that the circuit must be capable of operation with the cathode of the counter grounded, since, in this country at any rate, the majority of counters in use are of the end-window beta type with a metal envelope forming the cathode. While it is admittedly not impossible to operate the cathode of this type of counter at a negative potential with respect to ground, or to obtain a pulse from it to operate a quench circuit, it is often very inconvenient to do so. The alternatives are, therefore, to use a d-c coupled quench circuit, the majority of the components of which must be at a high positive potential, or to use an a-c coupled circuit. The first alternative is inconvenient because of the care needed in construction and the difficulty of supplying the necessary tube voltages from readily available sources. (This applies to the circuit described by den Hartog if the cathode of the counter is grounded). We therefore decided that the a-c coupled circuit would be more widely useful despite its inability to "rescue" a counter capable of going into a smooth discharge.

A circuit having the widest possible application would be one combining the advantages of both arrangements, but no such circuit seems to have been described to date. Where low-voltage counters are used, the problem is, of course, somewhat easier and den Hartog's ingenious circuit is very suitable.

Mr. K. Kandiah, of this establishment, has recently carried out some experiments, using the quench circuit described by us, with a Geiger-Müller counter containing no quenching agent, and the results so far obtained indicate that operation is satisfactory until a discharge happens to occur in the counter a few microseconds after the end of the quench period. At this time the voltage on the counter has risen above threshold, but the quench circuit has not yet recovered its normal sensitivity and such a discharge is therefore not quenched.

To obviate this effect, Mr. Kandiah has experimentally added an auxiliary flip-flop circuit with a relaxation time of about 10 μsec. This period is slightly longer than the period following the end of the quenching pulse during which the quench circuit is insensitive. The auxiliary circuit is triggered by every pulse delivered by the counter and generates a pulse 10 μsec later, which triggers the quench circuit if the latter has not already been triggered by the original pulse from the counter. Thus, on the rare occasions when the quench circuit is unable to rescue the counter immediately, it rescues it, in any case, 10 μsec after the discharge has begun.

Experiments, which are not yet complete, indicate that this expedient permits an a-c coupled quench circuit to be used reliably with a counter containing no quenching agent.

E. H. Cooke-Yarborough
Ministry of Supply
Atomic Energy Research Establishment
Harnwell, Didcot, Berkshire, England

Dear Sir:

May I call your attention to an erroneous statement on page 88 of the November, 1949, Nucleonics referring to "AEC, Notre Dame Sponsor New Atom Smasher." The two-million-volt electrostatic generator is not being built at Notre Dame, but is purchased from our company, the High Voltage Engineering Corporation here in Cambridge, Massachusetts.

Robert J. Caldwell
Radiation Division
High Voltage Engineering Corporation
Cambridge, Massachusetts

NUCLEONIC EVENTS

$817-MILLION BUDGET ASKED FOR OPERATION OF AEC

In his budget message delivered recently to Congress, President Truman called for an increase in the Atomic Energy Commission program to an estimated $817-million in 1951. This figure represents an increase of close to $196-million over the 1949 expenditures.* The message stressed increased defense requirements and also continued exploration of atomic energy for industrial and other peacetime purposes. Cost of the reactor program will jump from approximately $17-million in 1949 to close to $38-million in the 1951 estimate.

Actual weapons costs rise from $91-million to $115-million in 1950 and $144-million in the 1951 estimate. The AEC explains that the increase in the level of operations made possible by additional production and research facilities accounts for the higher costs estimated for 1951.

The operating costs of all materials and operations required to produce fissionable materials uranium-235 and plutonium show $109-million in 1949, $127-million in the 1950 estimate, and $139-million in the 1951 estimate. The AEC explains that as capacity is expanded at Oak Ridge, Hanford, and the feed-materials plants, the quantity of fissionable materials produced will continue to increase during 1950 and 1951. The increase in output during these fiscal years, it is expected, will be greater than indicated by the increase in cost because of process improvements and increased efficiency.

Emphasis will be placed on the development of new types of nuclear

* Expenditures of the AEC including salaries and expenses; atomic energy, executive allotment; payments from proceeds of sales, motor-propelled vehicles, *etc.*; working fund:

1949 *actual*	1950 *estimate*	1951 *estimate*
$620,937,630	$672,971,274	$816,754,000

Accrued Costs by Activities — U. S. Atomic Energy Commission

Description	1949 *actual*	1950 *estimate*	1951 *estimate*
Operations (accrued cost basis):			
(*a*) Source & fissionable materials	$108,672,317	$127,190,404	$138,753,767
(*b*) Weapons	90,654,326	115,056,626	143,979,563
(*c*) Reactor development	17,049,736	33,621,000	37,497,000
(*d*) Physical research	26,247,818	31,377,238	32,182,700
(*e*) Biology and medicine	14,660,545	18,983,042	20,139,418
(*f*) Community operations	14,507,018	8,053,548	7,440,680
(*g*) Program direction and administration	21,686,939	22,730,489	23,406,910
(*h*) Pay increases	—	505,435	713,567
Total	$293,478,699	$357,517,782	$404,113,605

reactors. Physical research, concentrating on the development of new basic information of value to developmental scientists and engineers in the field, shows an increase in cost from $26-million in 1949 to approximately $32-million in 1951. The program includes the production of radioisotopes at Oak Ridge for use in research and medical therapy. A substantial portion of the program of research in physical sciences is carried on at universities and other institutions. The Office of Naval Research has operated many of its contracts under AEC appropriations. Indications are that an increasing percentage of these contracts will come directly under the AEC management in 1951.

The program of biology and medicine runs approximately $15-million in 1949, $19-million in 1950, and $20-million in 1951. It comprises research in the effects of radiation, research in the fields of biology, biophysics and medicine, and dissemination of related unclassified information.

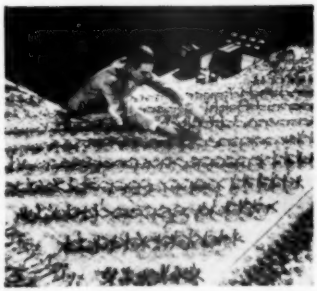
18 AEC-UNIVERSITY PROJECTS UNDERWAY IN HANFORD AREA

In a first-of-the-year report, the Hanford Operations Office of the AEC disclosed that 18 research projects costing $261,713 are underway at five educational institutions in that area. W. K. Crane, chief of the industrial health and instrumentation branch at Hanford, is responsible for administration of the contracts.

The research is being done almost entirely by faculty members and post graduate students.

University of Washington scientists are doing the investigation outlined in five of the contracts totaling almost $150,000. The largest of these calls for a $90,000 annual expenditure for fundamental studies approved on a five-year basis. Dr. L. R. Donaldson, director of the university's Applied Fisheries Laboratory, is in charge of basic studies on the effect of exposing fish to X-rays, the 1949 Bikini resurvey, and other research work. Dr. C. A. Finch is chief investigator of isotope studies in iron metabolism. Two meteorological projects, costing $16,100 and $14,768, are being conducted by Dr. P. E. Church and Dr. R. G. Fleagle. In the fifth contract, Dr. D. J. Hanahan has underway a $13,100 study of a C^{14}-labeled hormone

ABOUT THE COVER



IN MOST large-scale engineering projects, an operating model of the plant or device is first constructed to test the complete design. Because of the nature of a nuclear reactor, it is usually not feasible to do this. It is thus especially difficult to know how the various parts of the pile will react when running at high temperatures. Other test methods must be resorted to. The photograph on the front cover shows an electrical analog for study of temperature distribution in one section of the Brookhaven pile. The circuitry simulates a section of the pile, and various conditions of the circuit simulate the operating conditions of the pile. The current is the equivalent of heat flowing, voltage of temperature, and resistance of thermal resistance. Photo from Brookhaven National Laboratory

used in studies of the human body.

The State College of Washington has four investigations in progress, with a combined cost of almost $35,000. Dr. H. W. Dodgen is directing research involving ions in solution under a $9,600 contract, and Dr. M. Lindner is conducting an $8,910 experiment in a search for several unknown isotopes. Plant-life experiments costing $15,621 are being made by Drs. O. Biddulph and N. Higanbotham.

Reed College in Portland has four contracts calling for a total expenditure of some $40,000. The studies are being supervised by Drs. A. F. Scott, A. H. Livermore, and F. P. Hungate. Their work is in biology and physics and includes an AEC training course.

The University of Oregon is experimenting with radioisotopes under a $14,000 contract directed by Dr. P. L. Tisley. The university's medical school has three projects, totaling $14,557, being supervised by Drs. E. S. West and F. B. Queen.

Oregon State College scientists, Drs. T. H. Harris and John Huston, are experimenting with radioactive tracers as a $7,400 project. A second OSC contract for $4,500 provides for a study by Joseph Schulein in the separation of deuterium from hydrogen by means of zirconium metal.

AEC ANNOUNCES PROVISIONS FOR 1950–51 FELLOWSHIPS

The provisions under which the Atomic Energy Commission fellowship program will be administered by the National Research Council of the National Academy of Sciences during the 1950–1951 academic year were recently announced. Jointly developed by the AEC and the National Academy of Sciences, they are as follows:

1. No new predoctoral fellowships will be offered. The AEC plans to explore further the desirability of sponsoring in some way a predoctoral fellowship program in fields relating to atomic energy and intends to seek the advice of the National Academy of Sciences on this question.

2. New postdoctoral fellowships in the physical sciences, biology, biophysics, and medicine will be offered, but only for advanced training in fields of research closely related to the national atomic energy program wherein access to secret data is required or desirable. No new postdoctoral fellowships will be awarded until applicants have been investigated as to character, associations, and loyalty by the Federal Bureau of Investigation and granted full security clearance.

3. To fulfill previous commitments, applications for renewal of current non-secret predoctoral fellowships and postdoctoral medical fellowships will be accepted. Such renewals, however, will be granted only to applicants who have been investigated by the FBI and granted "fellowship approval" as to loyalty by the AEC, as required by the Independent Offices Appropriations Act for fiscal year 1950, which became effective August 24.

Under the program set up for this year, it is expected that about 75 new awards will be offered and about 175 renewals of current fellowships granted. Cost of the program during the next fiscal year is estimated to be between $600,000 to $900,000 depending upon the number of new awards that are actually made.

At present there are 421 AEC fellows, including 403 who are currently at work and 18 who will begin their studies within the next few weeks. Of these, 30 are engaged in research work requiring access to secret data and have therefore been granted full security clearance; and 391 are engaged

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NUCLEAR ENERGY GLOSSARY

NUCLEONICS, commencing in its March issue, will present selections from the "Nuclear Energy Glossary" to be published by the American Society of Mechanical Engineers under copyright by the National Research Council.

The terms in the March issue will be selected from the section on chemical engineering. Later issues will contain terms used in other phases of nuclear work.

in non-secret work. Of those in work of the latter type, 77 were appointed or reappointed after August 24, when the 1950 Appropriations Act took effect, and therefore have been investigated and granted fellowship approval as to loyalty; 314 were appointed before August 24 and therefore have only been required to sign the loyalty oath and non-Communist affidavit required of all fellows since May 22. Cost of the program during the current fiscal year will be about $1,500,000.

AEC Refuses Administration

In establishing the limited program for the 1950–1951 academic year, the AEC considered and rejected the possibility that the AEC itself take over administration of the program on its present basis for the following reasons:

1. The AEC believes any fellowship program affecting a substantial number of students training in broad and established fields of science should be administered by a scientific or educational organization. While an executive agency of the Government may properly sponsor such a program, the AEC feels it should not administer it.

2. The National Academy of Sciences, the senior agency for cooperation between the Government and the scientific community, has gone on record as opposing FBI investigation of fellows appointed to non-secret work. It would be difficult to administer an effective fellowship program that did not have the full support of the scientific community.

Health Physics Program

The AEC also announced today that the fellowships in health physics, formerly a part of the administered-by-NRC predoctoral program, now discontinued, will be continued in the next academic year although they will not be administered by the NRC. Alternate arrangements for the administration of the health physics program are now being worked out. Fellowship awards in health physics, of which there will be about 20 next year, will continue to be conditioned upon FBI investigation and full security clearance by the AEC, as they have been in the past.

The actions announced today do not affect the research work being carried on at the AEC's three national laboratories by graduate students. At present there are 15 such students at Brookhaven National Laboratory, 10 at the Argonne, and 7 at Oak Ridge.

U. OF MICHIGAN RESEARCH CONTINUED BY $7,200 GRANT

Grants have been made by the preliminary planning committee of the Michigan Memorial-Phoenix Project to further three University of Michigan research projects, it was recently announced.

Of a total grant of $7,200, $3,000 will go to continue a study by W. H. Beierwaltes of the effect of iodine on thyroid activity. Another $3,000 will make possible the continuation by H. R. Crane of his work to develop a super-Geiger counter to detect the C^{14} remaining in relics and thereby date historical remains from 1,500

to 25,000 years old. The remaining $1,200 will be used by R. J. Lowrey and R. C. Williams to continue chromosome investigations using P^{32}.

IRE CONVENTION SCHEDULES NUCLEAR SCIENCE SESSION

The 1950 National Convention of the Institute of Radio Engineers to be held at the Hotel Commodore, New York, March 6–9, will include on its afternoon program of March 6 a symposium on "Nuclear Science and the Radio Engineer."

The symposium speakers and their subjects will be: *News of the Nucleus*, by Urner Liddel; *Particle Accelerators*, by M. S. Livingston; *Radiofrequency Problems Associated with Particle Accelerators*, by J. P. Blewett; *Detection of Nuclear Radiations*, by J. R. Dunning.

INFORMATION-FOR-INDUSTRY GROUP STARTS AEC FILES SEARCH

A working party of representatives of the technical and engineering societies and business press, selected by the Atomic Energy Commission, recently began its examination of declassifiable technological information in the field of metallurgy with a view to determining its possible value to American industry (NU, Sept. '49, p. 80).

Members of this party are: Keith Henney, consulting editor of NUCLEONICS and *Electronics*, representative of the Institute of Radio Engineers; S. A. Tucker, American Society of Mechanical Engineers; F. J. Van Antwerpen, editor, *Chemical Engineering Progress*, American Institute of Chemical Engineers; Sidney Kirkpatrick, vice president, McGraw-Hill Book Co., Inc., editor, *Chemical Engineering;* E. E. Thum, editor, *Metals Progress*, American Society for Metals.

The men in this task force have been investigated and given security clearance to enable them to enter restricted areas and examine restricted files.

ANNOUNCEMENT

Remember the adage: Never point a gun at a man unless it is loaded.

American industry and all the American people together must cooperate in the light of the President's orders to accomplish an explosion by fusion—that is, to make an H-bomb.

I. Overclassification must stop.

II. The particles of modern industry—alphas, betas, gammas, neutrons and X-rays—must become as widely known and used as cars, radios and sports.

III. The monopoly of the people—"atomic energy"—must be exercised by all the people.

See the March NUCLEONICS.

—The Editor

67 PATENTS HELD BY AEC RELEASED FOR PUBLIC USE

Descriptions of 67 patents owned by the U. S. Government and held by the Atomic Energy Commission have been transmitted to the Patent Office for registry and listing in the *Official Register of Patents Available for Sale.*

WARTIME MEDICAL HAZARDS SUBJECT OF AEC COURSE

The Atomic Energy Commission, in cooperation with the National Security Resources Board and the General Services Administration, will sponsor a series of one-week "teacher training" courses in the medical hazards of atomic warfare for selected representatives of the medical profession, who in turn, it is expected, will instruct physicians, dentists and nurses in local areas as part of state and municipal civil defense programs.

The first of the courses will be held in March at the Argonne National Laboratory, Chicago; the Atomic Energy Project, Univ. of Rochester,

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Rochester; and Western Reserve Univ. School of Medicine, Cleveland. Later in the spring, courses will be offered at the Atomic Energy Project, Univ. of California at Los Angeles; the Univ. of Utah School of Medicine, Salt Lake City; the Univ. of Alabama School of Medicine, Birmingham; and Johns Hopkins School of Medicine, Baltimore.

U. OF CHICAGO-AEC PROJECT TO GET ACCELERATOR

A new Van de Graaff electrostatic accelerator for positive particles will be installed this year in the new quarters of the University of Chicago's Institute of Radiobiology and Biophysics. The High Voltage Engineering Corporation of Cambridge, Massachusetts, which recently received a contract to construct the accelerator, announced the apparatus will be unique in that the homogeneous beam of positive particles it will produce can be directed horizontally and vertically with sufficient ease to make possible alternate experiments normally requiring two such machines.

IN BRIEF

➤It is reported that Rep. Henry Jackson will sponsor an amendment to the McMahon Act that will facilitate fuller exchange of information between this country and Great Britain and Canada.

➤*The Atkinson-Jones Construction Co. has been awarded a contract for most of the construction work which will be undertaken in* 1950 *at the Hanford Works, which is operated by the General Electric Co. . . . It is reported that* $200,000,000 *will be spent on the expansion of Hanford.*

➤Despite pleas from many cancer patients all over the country, the University of Illinois Medical School has been forced to limit treatments with its 26-Mev betatron to residents of Illinois.

➤*AEC Commissioner Sumner T. Pike recently stated that the Government is spending* $7,800,000 *on the peaceful applications of atomic energy.*

➤According to Dr. Werner Heisenberg, famed German physicist, West German scientists will seek Allied permission to engage in nuclear research.

➤*Allan C. Johnson, chief of engineering and construction for Idaho Operations Office of AEC, states that tests show an adequate underground water supply for reactor test station at Arco.*

➤Wet sandblasting has been most effective method of decontaminating exposed Navy vessels. Nine out of ten of the Bikini targets ships have been decontaminated.

➤*The way to be best in science internationally, according to Arthur H. Compton, chancellor of Washington University, is through open interchange of ideas which should be carried out without release of Military secrets.*

➤One man, R. O. Dulaney, of Fort Worth, Texas, is now reported to own 75% of the productive uranium property on Colorado Plateau, chief U. S. source of the ore.

NUCLEAR NEWSMAKERS

Irving Langmuir, 1932 Nobel Prize winner for his work in surface chemistry, has retired from the General Electric Co. He will, however, continue work there as a consultant.

Walter S. Macauley, Rear Admiral, USN (retired), has been appointed assistant executive engineer of the Knolls Atomic Power Laboratory in Schenectady, N. Y., operated by the General Electric Company.

George B. Collins, now chairman of the department of physics at the University of Rochester, has been

(Continued on page 98)

PRODUCTS and MATERIALS

RADIOACTIVITY DEMONSTRATOR

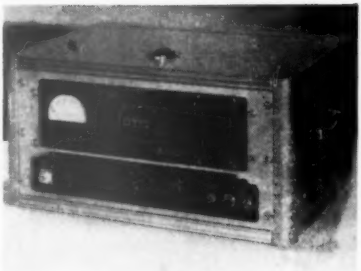
Nuclear Instrument and Chemical Corp., 223 W. Erie St., Chicago 10, Ill. The model 1613 radioactivity demonstrator, designed for classroom use, consists of a basic counting instrument, a 28-page manual, two radioactive sources, a set of lead, aluminum and paper absorbers, and a calibrated mounting device for positioning the latter. The counter provides three indications of activity: a neon flasher, audible clicks, and a rate meter.

PROPORTIONAL COUNTERS

Nuclear Measurements Corp., 3339 Central Ave., Indianapolis 5, Ind. Utilizing windowless counting chambers with full 2π geometry, the models PC-2A and PC-2B alpha and beta proportional counters have scaling factors of 8, 16, and 32 and maximum counting rates of 15,000 cpm. An alpha background of less than 1 cph is claimed for the PC-2A; its counting chamber accommodates a maximum sample area of 25 cm^2. The alpha plateau ranges from 700 to 1,000 volts with a slope of less than ½% in the best 100 volts. With a 1-in. diameter chamber bore, the PC-2B has a background of about 5 cpm. Automatic gas flow control and automatic timing up to 20 hours is provided in both models of this proportional counter.

IONIZATION CHAMBER METER

The Kelley-Koett Manufacturing Co., 12 E. 6th St., Covington, Ky. The Keleket model K-350 gamma survey meter utilizes a hermetically sealed ionization chamber and a five-range meter to measure 0–5, 0–50, 0–500, 0–5,000 and 0–50,000 mr/hr. Only one range is visible at a time on the scale-changing meter. Accuracy of 10% is claimed over an operating range from −10 to 125° F. The instrument is designed so that it can be zeroed in any radiation field.



DECADE SCALER

Tracerlab, Inc., 130 High St., Boston 10, Mass. Based on a scale-of-10, the SC-7 "100" scaler eliminates interpolation. Results are read directly from two columns of neon indicators and a mechanical register on the front panel. Two plug-in decade scaling units are used; four indicator lights, visible when the case is opened, indicate the actual position of each scale-of-2 in the feedback scale-of-10. Geiger-tube voltage supply is continuously variable from 350 to 2,200 volts. All power supplies are regulated, and change in output is less than 0.25% for a 1% change in line voltage. A plug-in discriminator input circuit, completely shielded to minimize spurious counts, is provided, as is a connection for an electric stopclock.

LIQUID FRACTION COLLECTOR

Microchemical Specialties Co., 1834 University Ave., Berkeley 3, Calif. The model 650 electric fraction collector is used in conjunction with models 651 and 666 interval timers for collecting fractions of any flowing liquids. The 651 timer generates pulses which control rotation and indexing of the collector reels. Reels of various diameters are available for handling different sizes and numbers of collecting containers. The model 666 timer is used to control operation of a magnetic flow valve, model 665, which acts as the liquid dispenser. Volumes from 0.5 to 50 ml may be dispensed at intervals of 1, 5, 15, 30, 60, or 120 min.

POWER SUPPLY

Furst Electronics, 12 S. Jefferson St., Chicago, Ill. With ½ kw maximum output, models 1110 and 1110A electronically regulated power supplies provide continuously adjustable d-c output voltages of 175–1,000 volts. Maximum current is 0.50 amperes for the model 1110; for the 1110A, 0.33 amperes. Output voltage is claimed to vary less than 5 volts for line voltage variations between 105 and 125 volts a-c, and a-c ripple voltage is claimed to be less than 20 millivolts. A voltmeter and an ammeter mounted on the front panel are permanently connected to the output terminals. The circuit is protected by fuses and an overload relay. The power supply weighs 185 pounds.

HIGH-VACUUM PUMP

Distillation Products Industries, 755 Ridge Road West, Rochester 13, N. Y. The model MCF-300 fractionating oil-diffusion pump provides a speed of approximately 300 liters per sec in the range 10^{-5} to 10^{-3} mm Hg. An ultimate vacuum of 5×10^{-7} mm Hg

at 25° C is attainable without cold traps. With a 4-in. inside diameter water-cooled pump casing, the new pump embodies a three-stage concentric-cylinder type of fractionating jet assembly fitted into an enlarged boiler. Because of the large boiler area, external heating units can be used without danger of burn-out.

TITANIUM TUBING

Superior Tube Co., Norristown, Pa. Commercially pure titanium tubing in sizes ranging from ¾ to ⅛ in. outside diameter is available in limited quantities. Impurities are held to less than 0.5%. Three standard tempers, annealed, half hard, and hard drawn, are being offered. The annealed tubing has a maximum ultimate strength of 80,000 psi and a minimum yield strength of 40,000 psi.

HIGH-VOLTAGE SUPPLY

Radio Corporation of America, Camden, N. J. Available with either positive or negative ground, the type EME-2 regulated high-voltage d-c power supply delivers a maximum current of two milliamperes over a voltage range of 10 to 50 kv. Voltage may be set by means of a fine control to within 10% of the selected voltage. Maximum ripple voltage is 5 volts; regulation of one part in output voltage is claimed. The unit is housed in two cabinets. All controls are on the driver unit, which contains a regulated d-c power supply, r-f oscillator, metering circuits, overload protection, and interlock circuits. The rectifier unit contains an r-f oscillator for heating the rectifier filaments, r-f tank circuits and voltage-tripling rectifier tubes, a series-resonant ripple trap, and a reference voltage divider. The two units are connected by four six-foot cables. Total weight is 150 pounds.

INSTRUMENT SERVICE

Atomlab, 489 Fifth Avenue, New York 17, N. Y., has completed laboratory facilities at Center Moriches, Long Island, for the repair of all makes of radioactivity detection and measuring equipment. Also, within 500 miles of New York City, Atomlab technicians will repair laboratory equipment under its field service plan.

LITERATURE AVAILABLE

Precision Spectrometer L124. Describes a new model divided-circle spectrometer which reads to one second of arc. Associated equipment is also detailed. *The Gaertner Scientific Corp., 1201 Wrightwood Ave., Chicago 14, Ill.*

Leak Detector Bulletin. The Consolidated Model 24-101A, a mass-spectrograph leak detector which uses helium as the probe gas, is described. Application to both pressure and vacuum systems is discussed. *Consolidated Engineering Corporation, 620 N. Lake Ave., Pasadena 4, California.*

Instrument and Control Valve Catalog 50. Variable-area primary flow meters, electrical and pneumatic transmitters, flow rate recorders, controllers, ratio controllers, totalizers and batch control systems are cataloged, together with air-operated diaphragm motor valves. *Fischer & Porter Co., 50 County Line Rd., Hatboro, Pa.*

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appointed chairman of the accelerator project at Brookhaven National Laboratory. He will replace **Milton G. White,** who has been on part-time leave from Princeton University and who now returns to fill the Higgins professorship in physics there. It is expected that Dr. Collins will assume his new duties in the Spring.

A processing advisory committee to assist in planning facilities for chemical and metallurgical operations at the reactor test station at Arco, Idaho, has been formed. It consists of: **F. W. Schumacher,** Westfield, N. J., associate director of Standard Oil Development Company, chairman, **Stephen Lawroski,** chief, Chemical Engineering Division, Argonne National Laboratory, Lemont, Ill.; **James Marsden,** chief, Chemistry Division, Knolls Atomic Power Laboratory, Schenectady, N. Y.; **F. L. Culler,** chemical engineer, Reactor Engineering Division, Oak Ridge National Laboratory, Oak Ridge, Tenn.; and **Dick Duffey,** chemical engineer, Reactor Development Division, AEC, Washington, secretary.

John K. Gustafson, who completed the two-year period he agreed to serve as manager of the AEC's Raw Materials Operations Office and recently resigned the post, will be succeeded by his deputy manager, **Jesse C. Johnson.** Dr. Gustafson will become consulting geologist of the M. A. Hanna Company, Cleveland, O.

Louis A. Turner, on completion of his 1949–50 academic year as head of the department of physics at The State University of Iowa, will assume new duties as director of the division of physics of Argonne National Lab.

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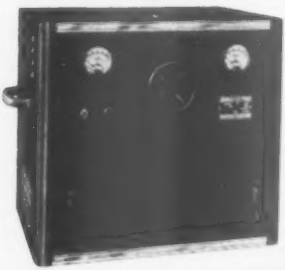

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